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Bellevue Urban Runoff Program, Washington
Summary Report

Bellevue Storm and Surface Utility, WA

Prepared for

Environmental Protection Agency, Washington, DC

Aug 84

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Bellevue Urban Runoff Program
SUMMARY REPORT

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This SUMMARY REPORT consolidates the major findings and conclusions of several individual studies, which included:

(1) Tests conducted to contrast the biological and chemical conditions in an urban creek with a rural creek.

(2) Monitoring urban runoff quality and quantity from 3 urban areas.

(3) Analysis of many source area, urban runoff, and creek samples for metallic and organic priority pollutants.

(4) Sampling of urban stormwater and base flows from 2 residential areas. Collection of street dirt samples and evaluation of effects of street cleaning and catchbasin cleaning on improvement of urban runoff quality.

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BELLEVUE URBAN RUNOFF PROGRAM

SUMMARY REPORT

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June 25, 1984

ABSTRACT

Many aspects of urban runoff in Bellevue, Washington were recently studied during a several year program that was funded by the U.S. Environmental Protection Agency (EPA) (Corvallis Lab, Storm and Combined Sewer Section, and the Water Planning Division through the Nationwide Urban Runoff Program - NURP), the U.S. Geological Survey (USGS), the Municipality of Metropolitan Seattle (METRO), and the City of Bellevue Storm and Surface Water Utility. It is the purpose of this report to consolidate the major findings and conclusions from each of the individual studies. The University of Washington conducted a series of tests to contrast the biological and chemical conditions in an urban creek with a rural creek. The urban creek was significantly degraded when compared to the rural creek, but still supported a productive, but limited and unhealthy salmonid fishery. Many of the fish in the urban creek, however, had respiratory anomalies. The urban creek was not grossly polluted, but flooding from urban developments has increased dramatically in recent years. These increased flows have dramatically changed the urban stream's channel, by causing unstable conditions with increased stream bed movement, and by altering the availability of food for the aquatic organisms. The aquatic organisms are very dependent on the few relatively undisturbed reaches. Dissolved oxygen concentrations in the sediments depressed embryo salmon survival in the urban creek. Various organic and metallic priority pollutants were discharged to the urban creek, but most of them were apparently carried through the creek system by the high storm flows to Lake Washington.

The USGS intensively monitored urban runoff quality and quantity from three residential areas in Bellevue. One of the areas was mostly an arterial street and had a series of small detention basins. Wet and dry atmospheric sources were also monitored by the USGS. The runoff quality was found to be much cleaner than found in other locations in the U.S. The detention basins were effective in reducing peak runoff flow rates by about 60 percent, but they were not effective in significantly improving the runoff quality.

METRO analysed many source area, urban runoff, and creek samples for metallic and organic priority pollutants. Concentrations in the creeks and in urban runoff were low, but source area samples had high concentrations of more priority pollutants. Polycyclic aromatic hydrocarbons (PAHs) and phthalate esters were the most commonly detected organic priority pollutants in the samples.

The City of Bellevue collected urban runoff and baseflow samples using flow-weighted techniques from more than 300 storms from two residential areas. They also collected many street dirt samples from these areas and evaluated the effects of street cleaning in improving urban runoff quality. Many sewerage particulate samples were also collected to estimate the effectiveness of sewerage cleaning. Most of the heavy metals were determined to originate from street dirt, but street cleaning was found to remove urban runoff pollutants by a maximum of only about ten percent. A special modified street cleaner was tested and found to be much more effective in removing the smaller sized street dirt that is washed off these streets by rains. Catchbasin cleaning twice a year was estimated to be about 25 percent effective, at the most.

The effects of urban runoff on receiving water aquatic organisms or other beneficial uses is very site specific. Different land development practices may create substantially different runoff flows. Different rain patterns cause different particulate washoff, transport, and dilution conditions. Local attitudes also define specific beneficial uses and desired controls.

Extensive, long-term projects are needed to effectively evaluate local urban runoff problems. Sediment transport, deposition, and chemistry play key roles in urban receiving waters and need additional research. Receiving water aquatic biological conditions, especially compared to unaffected receiving waters, should be studied in preference to laboratory bioassays.

ACKNOWLEDGMENT

I would like to acknowledge the valuable field work of David Renstrom, Joy Wherley, Susan Cezar and Laurie Murray, technicians with the City of Bellevue Storm and Surface Water Utility. Their care and commitment helped to make the successful completion of this project possible.

Pam Bissonnette, Director

TABLE OF CONTENTS

page

Abstract
Table of Contents

I. Executive Summary 1
- A. Introduction 1
  - 1. Project coordination 1
  - 2. Objectives 2
- B. Area Description and Climate 6
- C. Conclusions and Recommendations 12

II. Technical Report 23
- A. Effects of Urban Runoff 23
  - 1. Bellevue receiving water beneficial uses 24
  - 2. Bear and Kelsey Creeks water quality 25
  - 3. Creek gravel interstitial water quality 29
  - 4. Increased creek water flows 32
  - 5. Aquatic organism food availability and utilization 38
  - 6. Riparian vegetation 40
  - 7. Algae 40
  - 8. Benthic organisms 41
  - 9. Fish 45
  - 10. Creek sediment quality 49
  - 11. Lake Washington sediment quality 51
  - 12. Creek bank and streambed erosion 51
  - 13. Creek sedimentation and sediment transport 55
- B. Sources of Urban Runoff Pollutants 57
  - 1. Atmospheric particulate deposition and rain 57
  - 2. Runoff water sources 62
  - 3. Stormwater runoff quality 71
  - 4. Street dirt contributions to urban runoff discharges 87
  - 5. Sewerage and catchbasin sediment accumulations 103
- C. Urban Runoff Controls 111
  - 1. Street cleaning 111
  - 2. Sewerage inlet cleaning 122
  - 3. Detention Basins 125

III. Bellevue Storm and Surface Water Management Plan 134
- Appendix A Storm and Surface Water Utility Rate Ordinances 147
- Appendix B Natural Determinants Policies Draft 162
- Appendix C Citizen Action Requests 173

IV, References 174

TABLE OF TABLES

table		page
1.	Land Use Characteristics	8
2.	Typical Reported Water Quality Observations	15
3.	Typical Solids Quality	16
4.	Most Frequently Detected Organic Priority Pollutants in Solids	17,18
5.	Surrey Downs Deposition, Accumulation, and Washoff of Monitored Pollutants	20
6.	Surface Water Quality	26
7.	Annual Creek Discharges for June 1979 Through May 1980	28
8.	Seasonal Differences in Interstitial Streamwater Metals	31
9.	Monthly Discharge, Water Year June 1979 - May 1980	35
10.	Flood Frequency Estimates, Kelsey Creek	36
11.	Occurance of Benthic Macroinvertebrates in the Study Streams	42
12.	Metallic Priority Pollutants Found in Kelsey and Bear Creek Sediments	50
13.	Organic Priority Pollutant Observations in Kelsey and Bear Creek Sediments	52
14.	Metallic Priority Pollutants and Cyanides in Lake Washington Sediments	53
15.	Organic Priority Pollutant Observations in Lake Washington Sediments	54
16.	Major Cation and Anion Concentrations in Bellevue Rain	58
17.	Atmospheric Deposition Chemical Composition	59
18.	Metal Concentrations of Atmospheric Suspended Solids from the Duwamish Valley, Seattle	60
19.	Priority Pollutant Organic Compounds Detected on Atmospheric Suspended Solids from the Duwamish Valley, Seattle	61
20.	Annual Atmospheric Deposition	63
21.	Bellevue Rain Conditions during Project Period	65
22.	Urban Runoff and Base Flow Characteristics	67
23.	Variation of Runoff Coefficient (Rv) by Study Area, Season, and Rain Total	70
24.	Stormwater Major Anion and Cation Concentrations	73
25.	Urban Runoff Quality Reported by the USGS	75
26.	Urban Runoff Quality Reported by the City of Bellevue	76
27.	Metallic Priority Pollutants and Cyanide in Stormwater Reported by Metro	77
28.	Stormwater Insecticide and Herbicide Concentrations Reported by USGS	79
29.	Organic Priority Pollutant Concentrations in Stormwater Reported by Metro	80
30.	Stormwater Suspended Sediment Size Distributions	81
31.	Baseflow Water Quality Reported by the City of Bellevue	83
32.	Annual Stormwater Runoff Mass Yields Reported by the USGS	84
33.	Annual Baseflow and Stormwater Runoff Mass Yields Reported by the City of Bellevue	85
34.	Ratio of USGS to Bellevue Reported Stormwater Concentrations and Annual Mass Yields	86

TABLE OF TABLES (CONTINUED)

table page

35. Source Areas for Urban Runoff Pollutants 88
36. Street Dirt Chemical Characteristics 95
37. Metallic Priority Pollutants and Cyanide in Street Dirt 98
38. Organic Priority Pollutants Detected in Street Dirt 99
39. Approximate Annual Street Dirt Accumulation and Washoff 104
40. Stormsewer Inlet Structure Sediment Volumes and Accumulation Rates 105
41. Catchbasin Sediment Chemical Quality 106
42. Annual Accumulations of Sediments in Storm Sewer Inlet Structures 107
43. Bellevue Street Cleaning Costs 118
44. Effects of Street Cleaning on Runoff Loads 124
45. Priority Pollutant Concentrations Found in 148th Avenue South East Detention Basin Sediment 127

TABLE OF FIGURES

figure page

1. City of Bellevue, Washington Stream System and Study Sites 7
2. Population of Bellevue and Peak Annual Discharge in Kelsey Creek 33
3a. Hydrographs During a Winter Storm, Kelsey and Bear Creeks 37
3b. Hydrographs During a Summer Storm, Kelsey and Bear Creeks 37
4. Percent Composition and Abundance of Macroinvertebrates Sampled in Kelsey and Bear Creeks 43
5. Average Biomass of Fish at Sample Sites in Bear and Kelsey Creeks 46
6. Lake Hills Dry Season Rain/Runoff 68
7. Runoff Sources Surrey Downs - Wet Season 72
8. Urban Runoff Sources for Total Solids 89
9. Urban Runoff Sources for Lead 90
10. Surrey Downs - Without Street Cleaning 92
11. Dry Season Particle Size Distribution 93
12. Lead Conc. by Particle Size 96
13. Percent Washoff by Particle Size 101
14. Washoff Size Distribution 102
15. Surrey Downs - Ave. Sediment in Structures 108
16. Surrey Downs Street Loads 113
17. Street Cleaner Performance: Total Solids 114
18. Street Cleaner Performance: Particle Size 115
19. Total Solids - Dry Season - Lake Hills 120
20. Total Solids Concentration Comparisons 121
21. Load and Runoff Reductions 123

Conversion Factors

Given	multiply by	to obtain
lb/acre	1.134	kg/ha
lb/curb-mile	0.283	g/curb-meter
ft^3	0.028	m^3
mi	1.6	km
lb	0.454	kg
acre	0.4	ha
ft^3	28.3	l
ft	0.303	m

I. EXECUTIVE SUMMARY

A. INTRODUCTION

1. Project Coordination

A series of studies were conducted from 1978 through 1982 in Bellevue, Washington, to investigate Bellevue's urban runoff sources, effects, and potential controls. These projects were conducted by the City of Bellevue, the U.S. Geological Survey (USGS), the University of Washington, and the Municipality of Metropolitan Seattle (METRO). The project sponsors recognized the importance of coordinating these different projects early in their studies. The various project leaders were therefore able to coordinate their projects' activities to enhance the overall understanding of Bellevue urban runoff conditions.

This report is a summary of nine different project reports that were prepared by these various agencies. This report is specifically being prepared for the Nationwide Urban Runoff Program (NURP) of the Water Planning Division of the U.S. Environmental Protection Agency (EPA). This Bellevue information will be used along with results from 27 other cities throughout the U.S. in preparing a report to Congress describing urban runoff conditions, problems, and recommended controls nationwide.

The separate Bellevue projects were coordinated to address the three major phases in designing an urban runoff control program. These three phases include quantifying the specific local urban runoff receiving water problems, determining the sources of the problem pollutants, and selecting the most appropriate control measures. The USGS, through its Tacoma, Washington, office, conducted one of the projects which was funded by USGS and the Water Planning Division of EPA. The two reports prepared by the USGS and summarized in this report include Ebbert, et al, 1983 (ref. 1) and Prych and Ebbert, undated (ref. 6). The University of Washington's Civil Engineering Department and the College of Fisheries Research Institute prepared five reports based on their studies which were funded by the Corvallis Environmental Research Laboratory of EPA. These reports were prepared by Petersen, 1981 (ref. 3), Perkins, 1982 (ref. 4), Richey, et al, 1981 (ref. 7), Richey, 1982 (ref. 8), and Scott, et al, 1982 (ref. 9). The METRO report was funded by Region X of EPA and was prepared by Galvin and Moore, 1982 (ref. 2). The City of Bellevue also conducted a study which was funded by the Storm and Combined Sewer Section of EPA and the City of Bellevue. The Bellevue study report was prepared by Pitt, 1983 (ref. 5).

The Bellevue city project included monitoring of the quality and quantity of stormwater runoff from two urban areas in the City of Bellevue. Street surface particulate samples were collected in these two basins along with storm drainage sediment samples. The City of Bellevue conducted various street cleaning operations in the two test basins and evaluated the effectiveness of various types of street cleaning programs and catchbasin cleaning activities in improving the quality of urban runoff. The USGS also monitored stormwater runoff quality and quantity in these two test basins. The USGS used different sampling techniques to monitor fewer storms but in much greater detail. The USGS monitored rainfall and dustfall quality and quantity along with the performance of a series of detention basins at a third Bellevue test site. The University of Washington's projects investigated urban runoff receiving water conditions and conditions in a control stream much less affected by urban runoff. The University's projects studied physical, chemical, and biological conditions to identify impacts associated with urban development on receiving water quality. The Seattle METRO project involved conducting trace metal and organic pollutant analyses for samples collected from these three other projects.

These various projects collected a wealth of information concerning Bellevue's urban runoff and receiving water conditions. The purpose of this summary report is to consolidate the results from these separate projects into a single document. It is hoped that interested readers will acquire the separate reports for additional information that could not be included in this report. This summary report can only address the most important information needed to identify whether or not Bellevue has an urban runoff problem and the potential solutions. In order to facilitate examination of these other reports in more detail, the numerous references to these nine separate reports are identified in the text by their numbers (1 through 9) if necessary, and the appropriate pages or section numbers.

This report is separated into three main sections, each with numerous subsections. The first section is the executive summary which includes this introduction, a description of the objectives of the different projects, a description of the study area and its climate, and conclusions and recommendations. The second section of the report is the technical section which is separated into three discussions concerning the effects of urban runoff, sources of urban runoff pollutants, and urban runoff controls studied. This section contains discussions pertaining to the effects of urban runoff on Bear and Kelsey Creeks' water quality, algae, fish, etc. The discussion of sources of urban runoff pollutants is broken down into atmospheric sources, runoff quantity, runoff quality, street dirt sources, and sewerage and catchbasin sediment sources. The three urban runoff control measures studied were street cleaning, sewerage and inlet cleaning, and the use of detention basins. The third section of the report is a discussion of Bellevue's storm and surface water management plan. This discussion addresses the plan's objectives, implementation procedures, and the public education elements of the plan and general financing.

2. Project Objectives

A comprehensive study of urban runoff must include investigations of the effects of urban runoff, the sources of potential problem pollutants in urban runoff, and the controls available to reduce the problem pollutants. The projects comprising the Bellevue urban runoff program addressed these issues in a comprehensive manner. Generally, the University of Washington's projects evaluated the receiving water conditions for direct impairments of beneficial uses. Seattle METRO's project examined receiving waters and source contributions for toxic pollutants associated with urban runoff. The USGS characterized urban runoff discharges and evaluated the effectiveness of a detention facility. The City of Bellevue's study examined the sources of urban runoff pollutants from source and control areas in the watershed, characterized urban runoff discharges, and evaluated the effectiveness of street cleaning and sewerage and inlet cleaning. These projects all included other activities that complimented each other. Overall, a comprehensive evaluation of Bellevue's urban runoff conditions was made. This subsection itemizes the specific objectives stated for each of the major projects.

The University of Washington's projects (Pedersen, 1981; Richey, 1982; and Scott, Steward, and Stober, 1982) investigated receiving water conditions near the Bellevue test basins (Kelsey Creek) and in other locations unaffected by urban runoff (Bear Creek). The University of Washington project studied physical, chemical, and biological qualities of various receiving waters to identify impacts associated with urban developments on receiving water quality. Perkins (p.4) listed the specific objectives of the various Bellevue projects conducted by the University of Washington's Civil Engineering Department and Fisheries Research Institute. The specific objectives of these projects conducted by the University of Washington were as follows:

o Document the existing condition of the urban stream in terms of spatial and temporal variation in the distribution and abundance of aquatic organisms.

o Compare the condition of the urban stream with that of a less disturbed rural stream located in the same general area.

o Evaluate the effects of urbanization in terms of biological, physical, and chemical characteristics.

These objectives were designed to address the very difficult questions of identifying perceptible differences in the biota inhabiting the two streams. If differences existed, could they be considered impacts associated with urban runoff? If they were associated with urban runoff, what were the impact mechanisms?

The Seattle METRO project (Galvin and Moore, 1982) involved collecting urban runoff and other urban water and dirt samples for priority pollutant analyses. The other Bellevue projects were coordinated with the METRO project to supply samples for analysis. Galvin and Moore (p.2-1) stated that the goal of METRO's "Toxic Pollutant Inventory" was to define the presence of priority pollutants and other toxic pollutants in nonpoint water pollutant sources in order to assess potential problems and evaluate best management practices for their control. Their specific objectives were listed as follows:

o Identify toxic substances in urban runoff, their sources and concentrations in receiving waters.

o Conduct a comprehensive literature review concerning nonpoint sources of toxic substances.

o Use the information conducted in these first two tasks to assess the problem of toxic substances in urban runoff.

o Evaluate potential urban runoff control measures.

o Develop best management practices and an implementation plan to control toxic pollutants from nonpoint sources that are found in high concentrations in the Seattle/King County area.

o Initiate the implementation of the plan.

o Provide toxic substance data to the other Bellevue urban runoff projects and to the NURP program.

This report addresses just the first two of these objectives.

The USGS (Ebbert, Poole, and Payne, 1983; and Prych and Ebbert, undated) monitored storm runoff quality and quantity in two residential test basins. They used discrete sampling techniques to monitor selected storms in great detail over a two year period of time. The USGS monitored rainfall and dustfall quality and quantity along with the performance of a series of detention basins at a third Bellevue test site (148th Avenue SE). The USGS'objectives are described by Prych and Ebbert (p.20). These objectives included:

o to measure and define the temporal changes in quantity and quality of stormwater runoff;

o to use this characterization data to examine the differences that may result from street cleaning operations and detention facilities;

o to relate stormwater runoff quantity and quality to various precipitation and basin characteristics through available deterministic and statistic models;

o to use the models to evaluate the relative cost and effectiveness of the street cleaning and detention practices;

o to contribute to the development of more sophisticated and better automated systems for the measuring and sampling of urban stormwater runoff; and

o to contribute data to a national storage and retrieval system.

A major task in the City of Bellevue's project (Pitt, 1983) was monitoring the quality and quantity of almost all of the stormwater runoff from two residential basins that occurred during the two year project. Street surface particulate samples were collected in these two basins, along with selected storm drainage sediment samples. The City of Bellevue conducted various street cleaning operations in the two test basins, and statistically analysed the runoff quality data to detect any differences due to intensive street cleaning. Pitt (pp.1-1 and 1-2) described the objectives of the City of Bellevue's Storm and Combined Sewer Project. These objectives were as follows:

o Determine the effectiveness of street and sewerage cleaning in controlling urban runoff pollutants.

- Contribute urban runoff characterization information to the STORET National Water Quality Data Base.

- Examine the contributions of source area pollutant loadings to urban runoff discharges.

- Use the data as the beginnings of a more comprehensive data base for the whole city to support a water quality management plan.

Not all of the stated objectives were met during the course of the projects. Some of the needed information could not be obtained using the state-of-the-art methods that were available. However, other data was also collected to obtain a good understanding of the Bellevue urban runoff conditions.

B. AREA DESCRIPTION AND CLIMATE

Bellevue is a middle to upper middle class suburban community near Seattle, Washington. The city is decentralized, having residential areas served by shopping malls and numerous businesses along arterial streets. The population growth has been rapid in the past decade; the population in 1980 was about 74,000. Although the growth in Bellevue had largely occurred in residential areas, recent development has also included construction of additional office buildings and hotels. There is no heavy industry in Bellevue. Bellevue is within commuting distance of Seattle and is located on the other side of Lake Washington from Seattle. Lake Sammamish borders Bellevue on its east side. Bellevue receives about 1.1 meters of rain per year while substantially greater amounts of rain occur on the Olympic Peninsula to the west and much smaller amounts of rain occur in eastern Washington to the east.

Figure 1 shows the locations of the Bellevue test catchments in the City of Bellevue. The Surrey Downs and Lake Hills test catchments are about five kilometers (km) apart and are each about 40 hectares (ha) in size. They are both fully developed as largely single family residential areas. The 148th Avenue detention basin study area is about ten ha in area and is primarily a street arterial with adjacent landscaping. Table 1 (ref. 5, Table 3-1, and ref. 1, Table 2) summarizes the major surface and land use characteristics of these three areas.

The Surrey Downs basin is about 38 ha in size and includes the Bellevue Senior High School in addition to single family homes. The residential area was developed in the late 1950's. Most of the slopes in the basin are moderate with some steeper slopes on the west side of the basin. About 60 percent of the Surrey Downs basin is pervious. Back and front yards make up most of the land surface area of the basin, while the streets make up ten percent. The streets are generally in good condition with smooth to intermediate textures. There are a few locations where the curbs need repairing. Westwood Homes Road and 108th Street do not have curbs. There is relatively little automobile traffic in the Surrey Downs basin and the on-street parking density is low. The storm drainage system discharges into an artificial pond located in an adjacent development. This pond discharges into Mercer Slough which eventually drains to Lake Washington and Puget Sound. The Surrey Downs basin ranges in elevation from about 3 to 55 meters (m).

The Lake Hills catchment is about 41 ha in size and contains the St. Louise parish church and school in addition to single family homes. These homes were developed in the 1950's. Lake Hills has a slightly larger percentage of pervious area than Surrey Downs but a slightly smaller typical lot size. The slopes in Lake Hills are also more moderate (with a few exceptions) than those found in Surrey Downs. The street surface and gutter systems are also similar to those found in Surrey Downs. Most of the streets in Lake Hills also carry low volumes of traffic and have low parking densities, except for two busy roads which cross through the area. The Lake Hills storm drainage system discharges into a short open channel which joins Kelsey Creek just downstream from Larsen Lake. Kelsey Creek also discharges into Mercer Slough and finally to Lake Washington and Puget Sound. The elevation of the Lake Hills study area ranges from 80 to 125 m.

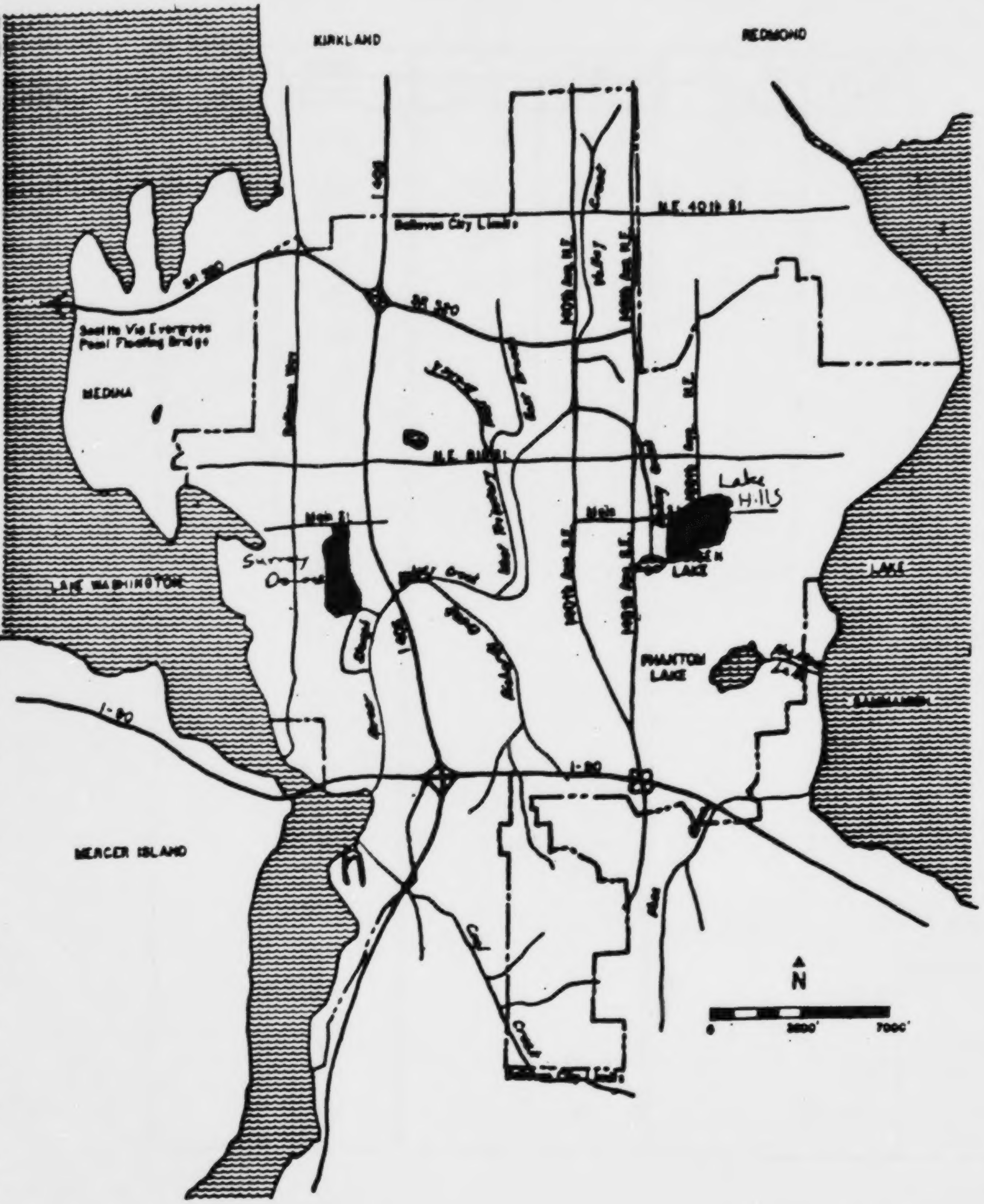

KIRKLAND
REDMOND
N.E. 40th St.
Bellevue City Limits
SR 520
Seattle Via Evergreen Point Floating Bridge
I-405
MEDINA
N.E. 8th St.
Main St.
Main
Lake Hills
Surrey Downs
LAKE WASHINGTON
LAKE
PHANTOM LAKE
SAMMAMISH
I-90
MERCER ISLAND
N
0
3500'
7000'

Figure 1 **CITY OF BELLEVUE, WASHINGTON**
STREAM SYSTEM and Study Sites

Table 1. Land Use Characteristics

	Surrey Downs		Lake Hills		148th Ave.	
	$10^6 ft^2$	%	$10^6 ft^2$	%	$10^6 ft^2$	%
Vacant	0.06	1.6	0	0	0	0
Parks	0.08	2.0	0.14	3.4	0.61	58.4
Backyards	1.45	37.1	1.52	36.5	NA	NA
Frontyards	0.89	22.8	1.01	24.4	NA	NA
Rooftops	0.67	17.1	0.79	18.9	NA	NA
Driveways	0.20	5.2	0.20	4.9	NA	NA
Parking Lots	0.15	3.9	0.01	0.2	NA	NA
Sidewalks	0	0	0	0	NA	NA
Streets	0.40	10.3	0.48	11.7	NA	NA
Total	3.90	100%	4.15	100%	1.05	
Area (acres)	95.1		101.7		25.7	
fraction impervious	0.40		0.35		0.57	
fraction pervious	0.60		0.65		0.43	
# of homes:	274		355		NA	
lot size:	0.3 (1)		0.25 (1)		NA	
frac. resid.	0.91		0.90		0.16	
frac. indus.	0		0		0	
frac. covered inst.	0.06		0.07		0.23	
fraction open area	0.03		0.03		0.61	
curb miles of streets	5.51 (2)		7.0		NA	

(1) acre

(2) Westwood Homes Rd: 0.5
108th Ave. S.E.: 1.5
cleaning area: 3.5)

The 148th Avenue S.E. catchment was used to investigate the effects of detention on stormwater quality. The area of this basin is about ten ha. Slightly more than one-fourth of this area is the actual street surface of 148th Avenue S.E., a divided, four lane arterial. Other impervious areas include sidewalks, parking lots, office buildings, and parts of Robins Wood Elementary School.

The soils in all three of these basins are mostly the Arents-Alderwood variety, having six to 15 percent slopes. The surface 200 millimeters (mm) is made up of gravelly sand loams with an estimated natural permeability of between 50 and 150 mm per hour. The total water capacity of this soil horizon is about 20 mm. The underlying horizon, ranging from 200 to 800 mm in depth, is made up of weakly to strongly consolidated till with a very low permeability (less than three mm per hour). About 25 percent of the Surrey Downs area is of the Ragnor-Indianola soil type which is moderately steep. The top 800 mm are a loamy, fine sand with a high permeability of between 150 and 500 mm per hour. The total water capacity of the surface horizon is about 80 mm. The 148th Avenue site is about one-third Alderwood gravelly-sandy loam of about 6 to 15 percent slope. The surface soil horizon is about 700 mm deep and also has a permeability of about 50 to 150 mm per hour. Because of its increased depth, this surface soil horizon has a total water capacity of about 60 to 80 mm.

A demographic survey was conducted in the Lake Hills and Surrey Downs catchments by the City of Bellevue at the beginning of the project. Slightly more than three people per household were reported in both basins while the population density per hectare was about 30 in Lake Hills and about 23 in Surrey Downs. Almost 25 percent of the households in Lake Hills had more than five people while only about 14 percent of the Surrey Downs houses had that many people per household. More than half of the people in both basins did not have any dogs or cats but the remainder of the households had one or more of each. Slightly more than two cars per household were reported with about ten percent of the households in each basin reporting four or more cars. About one-third of the households used unleaded gasoline while the remainder used leaded regular or leaded premium grades of gas. Most of the automobile oil was disposed of properly in the household garbage or recycled, but between five and ten percent of the households used oil to treat fenceposts, dumped it onto the ground, or into the storm sewers. Most of the people carried their grass and leaves to the dump or put them into the garbage and about one-third composted the organic debris on their lots.

Kelsey and Bear Creeks were selected by the University of Washington for their investigations (ref.4, pp.4 through 6). Kelsey Creek flows through the City of Bellevue while Bear Creek is about 30 kilometers further east. Kelsey Creek drains a watershed about 3200 hectares in area which is predominantly urban. About 54 percent of the Kelsey Creek watershed is in single and multiple family residences, 24 percent has commercial or light industrial uses, and 22 percent is parks and undeveloped. A main channel of Kelsey Creek starts at Larson Lake and flows about 12 kilometers through the City of Bellevue before discharging into Lake Washington. Three main tributaries (North Valley, West Tributary, and Richards Creeks) drain into Kelsey Creek. The subdrainages for these three tributaries constitute about two-thirds of Kelsey Creek's drainage. The USGS has continuously monitored Kelsey Creek flows since 1959 at a location about 2.5 kilometers upstream from Lake Washington. Kelsey Creek is a relatively narrow stream with a low slope. The mean channel slope is about one and one-half percent and the bank full width ranges from about three and one-half to six and one-half meters in the study area. Along much of its length, Kelsey Creek appears disturbed. Channelization, riprapping, storm drain outfalls, scoured and eroded banks, and culverts are common. The stream bank (riparian) vegetation is mostly composed of low growing alder and vine maple with scattered big leaf maples and western red cedar trees. The understory is dominated by blackberry bushes.

Bear Creek starts at Paradise Lake and drains into Cottage Lake Creek. Its drainage area is about 3400 hectares and is mostly rural in character. About 85 percent of the Bear Creek drainage is in pasture or woodlands with about 15 percent developed in single family residences. Two tributaries, Struve and Seidel Creeks, drain about 34 percent of the total Bear Creek drainage. Bear Creek also has a low slope (about 0.6 percent) and is slightly wider than Kelsey Creek with a bank flow width ranging from about seven to 11 meters. Bear Creek has the appearance of a relatively undisturbed stream, especially when compared to Kelsey Creek. The vegetation along some reaches in Bear Creek has been modified and there is some riprapping for bank stabilization. Most of these disturbances are quite small. Throughout most of the Bear Creek study reach the creek is composed of alternating series of pools and riffles, frequent debris dams, side channels, and sloughs. The riparian vegetation along Bear Creek is mostly old growth alder, western red cedar, and douglas fir, with an understory of vine maple and salmonberry. Richey (p, 17) states that while Bear Creek receives no "point-source" discharges, it is not pristine. Drainage from septic tanks, fertilizers, and livestock wastes have enriched the stream. Many homeowners had cut or modified the bank vegetation, installed small diversions, and created small waterfalls. These activities appear to have generated an increase in sediment transport in recent years. Building activity has also increased in the upper parts of the watershed since 1981. Much of the creek, however, remains in a natural condition and is typical of many of the gravel-bottomed streams in the Pacific Northwest.

The climate of Bellevue is influenced by Bellevue's proximity to Puget Sound. Bellevue's moderate climate has a mean annual precipitation of about 1.1 m which occurs mostly as rainfall from October through May (ref.6, p.27). Most of the rainfall results from frontal storms formed over the Pacific Ocean. During fall and winter months, low to moderate rainfall intensities are common. During the City of Bellevue's project period (ref.5, p.4-1) more than 200 rains were monitored at each of the Lake Hills and Surrey Downs basins. Rainfall monitoring began at Lake Hills in the middle of February, 1980, and about two weeks later at Surrey Downs. The rainfall monitoring was completed at the end of January, 1982 at both locations. The total annual rainfall during the study averaged about 0.93 m with about 108 rain events per year. A dry season lasts from about the first of March to the end of September. During this dry time, the monthly rain totals were less than about 75 mm while the wet season, which lasts from the first of October to the end of February, had monthly rain totals between 75 and 150 mm. Each storm during the wet season had about twice as much rain as the individual storms during the dry season. The wet season rains also lasted about one and one-half to two times as long as the dry season rains. The average rain per storm for the whole year was about 8.6 mm, lasting about eleven hours. The preceding dry period averaged about six days for the complete year but could be as long as several weeks during August. The annual average rain intensity was about one mm per hour, while the peak 30-minute rain intensity observed during the complete project was about 4.8 mm per hour. The average rain conditions at Lake Hills and Surrey Downs were quite similar, but individual rain pairs had quite varying conditions. The total rain and duration values for the two sites varied by as much as ten times. About half of the rains that were observed simultaneously at both basins had a difference in rain quantity greater than plus or minus 20 percent. This difference was much greater for the small rain events than for the larger rain events. When the resultant runoff yields from the two basins are compared for a specific storm, differences in observed rain conditions may be more important than differences in control measure applications.

C. CONCLUSIONS AND RECOMMENDATIONS

The most important element in an urban runoff study is defining and recognizing an urban runoff problem. It is not very effective to implement a control program that does not reflect the specific problems and the measured or assumed cause and effect relationships. The easiest way to identify problems is to examine the established and accepted beneficial uses of the receiving waters. If these uses are degraded, then cause and effect relationships need to be investigated. This difficult and sometimes inconclusive analysis frequently provides a rationale for the control program. This conclusion discussion, therefore, is separated into discussions of the beneficial uses, the observed impairments of these beneficial uses, possible cause and effect relationships, and, finally, the effectiveness of the monitored control measures. The technical section of this report presents summaries of the data supporting these conclusions.

Beneficial Uses and Urban Runoff Problems

Bellevue area waters, including Kelsey Creek, have five beneficial uses. These beneficial uses are as follows:

1) preservation of habitat suitable for aquatic organisms
2) flood prevention by the conveyance of stormwater
3) open space and resource preservation
4) recreational uses (swimming and boating)
5) aesthetics.

All of these beneficial uses were found to be degraded, to various extents, in Kelsey Creek. The following discussion summarizes these problems.

Degradation of Habitat, Observations:

o The urbanized Kelsey Creek environmental quality was much better than expected, but was degraded when compared to the less urbanized Bear Creek. Kelsey Creek apparently lacked gross contamination by pollutants. The direct toxic effects of pollutants during storms appeared to be small; the stream did support a small, but unhealthy, salmonid population. Kelsey Creek salmon did grow faster than Bear Creek salmon, however.

o The fish population in Kelsey Creek had adapted to its degrading environment by shifting the species composition from coho salmon to less sensitive cutthroat trout and by making extensive use of less disturbed refuge areas.

o Studies of damaged gills found that up to three-fourths of the fish in Kelsey Creek were affected with respiratory anomalies, while no cutthroat trout and only two of the coho salmon sampled in Bear Creek had damaged gills.

o Massive fish kills in Kelsey Creek and its tributaries were observed on several occasions during the project due to the dumping of toxic materials down the storm drains.

o There were significant differences in the numbers and types of benthic organisms found. Mayflies, stoneflies, caddisflies, and beetles were rarely observed in Kelsey Creek but were quite abundant in Bear Creek. These organisms are commonly regarded as sensitive indicators to environmental degradation. By comparison, Kelsey Creek fauna was dominated by Oligochaetes, Chironomids and amphipods, commonly regarded as species more tolerant to environmental degradation.

o As an example of a degraded aquatic habitat in Kelsey Creek, a specie of clams (Unionidae) was not found in Kelsey Creek, but was found in Bear Creek. These clams are very sensitive to heavy siltation and unstable sediments. Empty clam shells, however, were found buried in the Kelsey Creek sediments indicating their previous presence in the creek and their inability to adjust to the changing conditions.

o The benthic organism composition in Kelsey Creek varied radically with time and place while the organisms were much more stable in Bear Creek.

Degradation of Habitat, Possible Causes:

o These aquatic organism differences were probably mostly associated with the increased peak flows in Kelsey Creek caused by urbanization and the resultant increase in sediment carrying capacity and channel instability of the creek.

o There was also the potential for accumulation of toxic materials in the stream system affecting aquatic organisms; but only low concentrations of toxic materials were found in the receiving waters.

o The concentrations of dissolved oxygen in the urban creek's gravel waters were quite low and may have decreased the survival of salmon embryos. Instream embryo bioassays indicated that coho embryo salmon survival was significantly greater in Bear Creek than in Kelsey Creek, but no difference was found when using rainbow trout embryos.

o Direct receiving water effects from urban runoff may not have been significant for most storms. Potential long term problems, however, may be associated with settleable solids, lead, and zinc. These settled materials may have silted up spawning beds and introduced high concentrations of potentially toxic materials directly to the sediments. The oxygen depletion observed in the interstitial waters was probably caused by organic sediment buildup from runoff events.

o Kelsey Creek had much lower flows than Bear Creek during periods between storms. About 30 percent less water was available in Kelsey Creek during the summers, even though both creeks have drainage basins of similar size, rainfall characteristics and soils. These low flows may also have significantly affected the aquatic habitat and the ability of the urban creek to flush toxic spills or other dry weather pollutants from the creek system.

o Kelsey Creek had higher water temperatures (probably due to reduced shading) than Bear Creek. This probably caused the faster fish growth in Kelsey Creek.

Conveyance of Stormwater:

o Kelsey Creek had extreme hydrologic responses to storms. Flooding substantially increased in Kelsey Creek during the period of urban development;

the peak annual discharges almost doubled in the last 30 years, and the flooding frequency also increased due to urbanization.

o These increased flows in urbanized Kelsey Creek resulted in greatly increased sediment transport and channel instability.

Open Space and Resource Preservation Beneficial Uses:

o The lack of adequate buffer zones and natural creek banks along much of the urban reaches of Kelsey Creek is balanced by extensive park system developments along selected reaches. Natural creek reaches are very important for the aquatic organisms in Kelsey Creek.

o Creek bank-side homeowners have made extensive channel and riparian vegetative changes which significantly reduced the ability of the creek to support aquatic life.

Recreational Beneficial Uses:

o The natural small size of Kelsey Creek restricts its usefulness for most water contact related activities, although swimming does occur in the lower reaches of Kelsey Creek during the summer.

o The fecal coliform bacteria populations in Kelsey Creek were high, and variable. These organisms indicate the potential presence of pathogenic bacteria and commonly exceeded water contact numeric criteria.

Aesthetics Beneficial Uses:

o This use is related to most of the above uses; unsightly creeks are not utilized in educational field trips or as swimming areas, or desired as amenities to property.

o Dead fish from periodic toxic material spills significantly degrade this use.

o Debris and unstable channels also adversely affect the aesthetic quality of Kelsey Creek.

Sources of Urban Runoff Problems (tables 2, 3 and 4 summarize the available water and source area particulate quality data)

Increased Flows:

o For all rains greater than about 2.5 mm (0.1 inch), the impervious surfaces (streets, sidewalks, driveways, parking lots, and rooftops) were found to contribute more than 60 percent of the total urban runoff flows. The remainder of the flows were approximately evenly divided between front and back yards, while vacant lots and parks contributed very little to the flows due to their limited presence in the test areas. For most of the rain events monitored, the street surfaces contributed about 25 percent of the total urban runoff flows.

Sources of Pollutants:

Table 2. Typical Reported Water Quality Observations

constituents, mg/l unless noted otherwise	precipitation		urban runoff baseflow		urban runoff storm flow		Bear Creek stable flow surface water		Kelsey Creek stable flow surface water	
	typical	range	typical	range	typical	range	typical	range	typical	range
hardness, as $CaCO_3$	1	0→1	-	-	24	7→170				
alkalinity, as $CaCO_3$	1	-	-	-	12	<1→25				
spec. cond., μmhos/cm	18	6→76	260	140→430	41	12→1480				
pH, pH units	4.4	2.8→5.4	-	-	6.5	3.4→7.9				
total dissolved solids (TDS) (by spec. cond.)	3	<1→44	-	-	35	8→788				
suspended solids (SS)	3	<1→21	-	-	50	1→2740	4.7	0.8→12	11	2.5→33
total solids (TS)	~ 6	-	200	110→330	110	24→620				
chemical oxygen demand (COD)	11	1→113	23	6.8→67	46	8→780				
biochemical oxygen demand - 5 day (BOD_5)	-	-	-	-	6.6	<0.1→40	1.6	0.03→3.6	2.3	0.86→6.3
total organic carbon (TOC)	~ 2	-	-	-	~ 10	-				
total Kjeldahl nitrogen (TKN)	0.45	0.12→1.8	0.8	0.2→2.4	1.0	0.21→45				
ammonia, as N (NH_3)	0.09	<0.001→0.31	-	-	0.14	<0.01→7.2				
nitrite plus nitrate, as N (NO_2+NO_3)	0.13	<0.01→3.6	-	-	0.21	<0.01→4.5	0.50	0.06→2.4	0.74	0.46→0.96
total phosphorus (TP)	0.008	<0.001→0.16	0.16	0.027→1.2	0.26	0.01→9.2	0.01	0.015→0.08	1.2	0.07→1.9
arsenic (As) μg/l	-	-	-	-	13	3→37				
cadmium (Cd), μg/l	-	-	-	-	0.7	<0.1→1.9				
chromium (Cr), μg/l	-	-	-	-	7	2→19				
copper (Cu), μg/l	-	-	-	-	20	4→46				
lead (Pb), μg/l	11	<1→2,300	<100	<100→100	170	4→1800				
zinc (Zn), μg/l	-	-	90	26→470	110	30→370				

(1) Typical values are summarized from the various reports and are either means or medians.

Table 3. Typical Solids Quality

typical(1) dry-weight concentrations (mg constituent/kg total solids)

Constituent	atmos. suspended solids	street dirt	catchbasin sediment	detention basin sediment	Kelsey Creek(2) sediment (median-course)	Bear Creek(2) sediment (median course)	Lake Washington sediment(2)
COD	-	150,000	130,000	-	-	-	-
TKN	-	1,500	2,100	-	-	-	-
TP	-	560	690	-	-	-	-
As	200	25	-	19	30	25	20
Cd	13	1	-	1	0.3	0.1	0.3
Cr	98	97	-	20	150	50	50
Cu	510	93	-	35	15	10	30
Pb	1050	820	870	600	10	5	100
Hg	3	0.06	-	0.11	-	-	0.1
Ni	110	32	-	20	30	20	30
Zn	1600	160	320	310	100	70	100
CN	-	0.2	-	0.18	-	-	0.3

(1) typical values are means, or medians, as reported in the various reports.

(2) wet-weight values originally, the dry weight estimates shown are about three times the wet weight values.

Table 4. Most Frequently Detected Organic Priority Pollutants in Solids

constituents μg constituent/kg total solids	Atmospheric Suspended Solids (2 samples)			Residential Street Dirt (7 samples)			Detention Basin Sediments (one sample only)
	median	range	occurrance	median	range	occurrance	value
Pesticides:							
α-BHC	-	-	ND	14	10-18	2/7	0.45
β-BHC	-	-	ND	-	-	ND	0.19
γ-BHC (Lindane)	-	-	ND	25	6-43	2/7	0.42
4,4' DDE	4.6	-	1/2	-	-	ND	ND
endosulfan sulfate	25	-	1/2	-	-	ND	ND
endrin	12	-	1/2	-	-	ND	ND
Halogenated Aliphatics:							
trichloromethane	-	-	ND	5	4-15	4/7	ND
tetrachloroethene	-	-	ND	24	16-32	2/7	ND
Monocyclic Aromatics:							
ethylbenzene	-	-	ND	5	5-25	3/7	ND
toluene	-	-	ND	5	4-8	3/7	120
Phenolics:							
phenol	-	-	ND	100	80-470	3/7	ND
pentachlorophenol	1,700	-	1/2	1800	120-3,400	2/7	ND
2,4-dimethylphenol	-	-	ND	20	10-30	2/7	ND
4-nitrophenol	2,300	-	1/2	-	-	ND	ND
Phthalate Esters:							
diethyl phthalate	22,000	-	1/2	180	160-890	3/7	ND
di-n-butyl phthalate	1,200	-	1/2	520	490-2400	3/7	ND
di-n-octyl phthalate	3,000	-	1/2	970	-	1/7	ND
butyl-benzyl phthalate	-	-	ND	800	220-35,000	4/7	ND
bis-2-ethylhexyl phthalate	4,900	-	1/2	20,000	11,000-24,000	3/7	ND
PAHs:							
benzo(a)anthracene	4,450	1,900-7,000	2/2	660	-	1/7	1,100
benzo(k)fluoranthene	8,100	4,200-12,000	2/2	1,400	280-1,400	3/7	ND
benzo(a)pyrene	2,400	1,700-3,000	2/2	360	80-640	2/7	ND
chrysene	5,200	1,400-9,000	2/2	1,000	210-2,000	5/7	2,000
indeno (1,2,3-ed) pyrene	8,900	720-17,000	2/2	-	-	ND	ND
phenanthrene	2,000	-	1/2	880	180-1,900	7/7	2,100
pyrene	2,700	1,400-4,000	2/2	1,400	320-2,400	6/7	3,000
fluoranthene	720	-	1/2	1,200	740-2,600	7/7	2,500

Table 4. Most Frequently Detected Organic Priority Pollutants in Solids (page 2)

constituents μg constituent/kg total solids	Kelsey Creek Sediments (2 samples)			Bear Creek Sediments (2 samples)			Lake Washington Sediments (12 samples)		
	median	range	occurrance	median(1)	range	occurance	median	range	occurance
Pesticides:									
α-BHC	-	-	ND	-	-	ND	-	-	ND
β-BHC	-	-	ND	-	-	ND	-	-	ND
γ-BHC (Lindane)	-	-	ND	-	-	ND	0.42	-	1/12
4,4' DDE	-	-	ND	-	-	ND	2.4	2.2-2.6	2/12
endosulfan sulfate	-	-	ND	-	-	ND	-	-	ND
endrin	-	-	ND	-	-	ND	-	-	ND
Halogenated Aliphatics:									
trichloromethane	-	-	ND	-	-	ND	-	-	ND
tetrachloroethene	-	-	ND	-	-	ND	71	-	1/12
Monocyclic Aromatics:									
ethylbenzene	-	-	ND	-	-	ND	-	-	ND
toluene	-	-	ND	-	-	ND	150	7-300	2/12
Phenolics:									
phenol	-	-	ND	-	-	ND	-	-	ND
pentachlorophenol	-	-	ND	60	-	1/2	-	-	ND
2,4-dimethylphenol	77	-	1/2	100	-	1/2	-	-	ND
4-nitrophenol	-	-	ND	-	-	ND	-	-	ND
Phthalate Esters:									
diethyl phthalate	-	-	ND	-	-	ND	-	-	ND
di-n-butyl phthalate	-	-	ND	-	-	ND	-	-	ND
di-n-octyl phthalate	-	-	ND	-	-	ND	-	-	ND
butyl-benzyl phthalate	320	-	1/2	720	-	1/2	-	-	ND
bis-2-ethylhexyl phthalate	39	-	1/2	-	-	ND	-	-	ND
PAHs:									
benzo(a)anthracene	-	-	ND	-	-	ND	61	-	1/12
benzo(k)fluoranthene	79	-	1/2	-	-	ND	54	-	1/12
benzo(a)pyrene	38	-	1/2	-	-	ND	-	-	ND
chrysene	72	-	1/2	-	-	ND	-	-	ND
indeno (1,2,3-ed) pyrene	-	-	ND	-	-	ND	-	-	ND
phenanthrene	38	26-50	2/2	-	-	ND	-	-	ND
pyrene	56	28-83	2/2	-	-	ND	54	51-83	3/12
fluoranthene	51	30-72	2/2	-	-	ND	72	-	1/12

(1) the median for only 2 values is the average.

- o Most of the total solids in urban runoff originated from front and back yards in the test areas. The street surfaces contributed only a small fraction to the total solids of urban runoff discharges. Lead, zinc, and COD, however, were mostly contributed from street surfaces. Nutrients (phosphorus and total Kjeldahl nitrogen) were found to originate mostly from street surfaces, driveways, and parking lots combined.

o Pesticides were only found in the residential street dirt samples, and not in the arterial, commercial, or industrial street dirt samples. The arterial street dirt samples had much higher concentrations of lead, most likely due to increased automobile activity.

o Many organic priority pollutants were detected in the soil samples. The most important organics found were the polycyclic aeromatic hydrocarbons (PAHs), which were frequently detected in the street dirt samples and the Kelsey Creek sediment samples.

o Motor vehicle activity was expected to be the primary contributor of most of the toxic organic and inorganic priority pollutants. Gasoline and diesel fuel combustion products, lubricant and fuel leakages, and wear of the vehicles affected the street dirt material most significantly.

o Almost as much of the street dirt was lost to the air, as suspended particulates, as was washed off during rain events.

Availability of Pollutants to Runoff:

o The maximum observed runoff event discharged about 25 percent of the total pollutants that were on the street surfaces and in the catchbasins and sewerage combined. Therefore, most urban runoff pollutants were not source limited. However, those particulates that were most available for washoff (the smallest particles) might be source limited. About one-half of the total annual urban runoff discharges might be residing on the street surfaces and tied up in catchbasins and storm drainage sediments at any one time. If the Bellevue rain events were capable of removing more of this material, then the urban runoff discharges would be much greater than observed (Table 5).

o Only a small fraction of the total particulate loadings on the impervious surfaces was removed by the rains (about 15 percent). Large particles were not effectively removed, while about one-half of the smallest particles (less than 50 microns) were washed off during rains. These small particles were not very abundant, but had very high heavy metal and nutrient concentrations.

o Most of the settled particulate material in the storm drainage inlets and sewerage pipes was not removed by the observed storms.

Control of Urban Runoff

Street Cleaning

o Intensive street cleaning (three times a week) resulted in rapid and significant decreases in street surface loadings; from about 110 gm/curb-meter down to about 55 gm/curb-meter. The median particle sizes also decreased significantly with intensive street cleaning. A regenerative air street cleaner

Table 5. Surrey Downs Deposition, Accumulation, and Washoff of Monitored Pollutants

"Sources"	unit area value (kg/ha/yr)					
	total solids	COD	TKN	total phosphorus	Lead	Zinc
Atmospheric Deposition						
rain	32	-	4	0.1	0.1(recover.)	-
particulate (dry)	88	76	2	0.2	0.2(recover.)	-
Street Dirt						
accumulation	200	25	0.2	0.1	0.1	0.03
washoff	30	3	0.04	0.02	0.02	0.006
lost to air	20	2	0.02	0.01	0.01	0.003
Storm Drainage Inlet accumulation	150	40	0.2	0.3	0.5	0.1
Urban Runoff						
baseflows	110	11	0.6	0.1	0.03	0.06
stormwater	210	90	1.8	0.4	0.26	0.24
Kelsey Creek Discharges	300(sus)(1)	-	-	0.9	-	-
Bear Creek Discharges	80(sus)(1)	-	-	0.3	-	-

(1) Suspended solids only

showed substantially better performance in removing the finer street surface materials than the regular mechanical street cleaner.

o Extensive data analysis did not show any significant improvements in runoff water quality during periods of intensive street cleaning. The street cleaning operations tested are only expected to improve runoff quality by a maximum of about ten percent. The street cleaning equipment preferentially removed the larger particle sizes, while the rain events removed the finer materials. Street cleaning was not very effective in removing the available particulates.

o Mechanical broom street cleaning was effective in removing the larger litter from the streets.

o Infrequent street cleaning may result in significant increases in fugitive dust losses to the atmosphere.

Storm Drainage Inlet Cleaning:

o After an initial cleaning, it required almost a full year for sediment to reach a stable volume in the inlet structures. Only about 60 percent of the total available sump volumes in inlets and catchbasins were used for detention of particulates at the stable volume. At any larger storage levels, the rains were effective in controlling the volumes. Cleaning the inlets and catchbasin sumps about twice a year was expected to reduce the lead and total solids urban runoff concentrations by between ten and 25 percent. COD, the nutrients, and zinc might be controlled between five and ten percent.

Detention Basins:

o The small detention basin tested (detention time of 30 minutes, or less) did not have any significant effect on urban runoff quality.

o The small detention basin did have a significant effect on the peak flow rates. The peak flow rates were reduced by about 60 percent.

Summary

These studies indicated the very significant interrelationships between the physical, biological, and chemical characteristics of the urbanized Kelsey Creek system. The aquatic life beneficial uses were found to be impaired and stormwater conveyance was found to be significantly stressed by urbanization. These degradations were most likely associated with increased flows from the impervious areas in the urban area. Changes in the flow characteristics could radically alter the ability of the stream to carry the polluted sediments into the other receiving waters. If the stream power of Kelsey Creek was reduced, then these toxic materials could be expected to be settled into its sediment, with increased effects on the stream's aquatic life. Reducing peak flows would also reduce the flushing of smaller fish and other aquatic organisms from the system.

If detention basins were used to control peak flows, they would have to be carefully located and designed so that increased flow rates did not occur in downstream areas. The placement of flow modifying structures throughout the watershed could significantly affect the response time of the watershed to rain events, with possible resultant increases in downstream peak flows.

It was found that substantial quantities of water originated from the impervious areas in the developed areas. More careful planning to increase the perviousness of these areas should also be considered.

Another recommendation is to preserve any of the refuge areas in Kelsey Creek and to carefully design any channelization project to include refuge areas for the aquatic life. Because of the larger potential for sedimentation of toxic pollutants in Kelsey Creek, increased awareness of the beneficial uses and undesirable discharges to the drainage system will be more important. The large assimilative capacity of the water bodies that currently receive most of these pollutants are currently masking this concern.

Many recommendations concerning the public works practices in the Bellevue area can also be made based on this project. However, their effects on improving the urban runoff quality would probably be quite small. If intensive street cleaning was implemented, along with semi-annual catchbasin sediment cleaning, urban runoff discharges for most pollutants would be reduced by about ten percent while some of the heavy metal discharges may be reduced by as much as 25 percent. Even though these reductions are quite small, they may be important to reduce the accumulation of these highly polluted sediments in the smaller creek systems, especially if peak flushing flows are reduced.

II. TECHNICAL REPORT

A. EFFECTS OF URBAN RUNOFF

The primary element in an urban runoff study is to first identify an urban runoff problem. Unless the urban runoff problem is understood and documented well, there is little hope that the proposed urban runoff control plan would be effective. Defining an urban runoff problem entails considerable research. In order to acknowledge the extance of an urban runoff problem the beneficial uses of the receiving waters must be clearly defined and accepted; then field investigations can be conducted to determine if these beneficial uses are being met. If the uses are not being met, then a problem exists and it is necessary to determine the causes. The identification of potential causes can be very straightforward (such as the presence of large concentrations of toxic materials or a poor physical habitat). The difficult aspect, however, is determining the cause and effect relationships in order to estimate how much control or improvement of these degrading factors is necessary before the beneficial use criteria can be met. The various studies associated with the University of Washington's Bellevue project examined existing conditions in Kelsey Creek, the urban receiving water, as compared with Bear Creek, a less developed water. Their project considered many aspects of the receiving water (chemical, physical, and biological characteristics). The other three Bellevue urban runoff projects all have important characterization aspects. These projects attempted to identify potential problem pollutants by comparing observed runoff water quality with beneficial use water quality criteria and with concentrations found in other waste streams and receiving waters. This runoff characterization information can be used in a preliminary assessment to identify potential problem pollutants or physical mechanisms. The unique assimilative capacities for the Bellevue receiving waters must also be considered.

Richey (pp. 5 through 7) summarizes some of these problems that the University of Washington study team addressed. Urbanization and stormwater runoff discharges to streams can have a wide variety of effects on these receiving waters. These include increased runoff, decreased surface storage, decreased transpiration, decreased infiltration, and a degradation in water quality. These effects may either be long term or intermittent. Changes in channel geomorphology caused by channelization in the clearing of stream bank vegetation may cause permanent stresses to the stream. Changes in the stream flows during runoff events, such as rapidly rising and falling hydrographs and increased total flows and peak discharges, are intermittent stress factors. The discharge and transport of pollutants can act as an intermittent stress factor, but the storage of these pollutants in the stream system (in the sediments or bioaccumulation) can act as a long term or chronic stress factor. Therefore, it is necessary to not only identify the causative factor in impairing receiving water quality but also the times when these effects occur. Elevated concentrations of toxic materials in the runoff may affect receiving water organisms during a runoff event. However, they may also accumulate in the sediments and not affect the receiving water aquatic life until some time after they were discharged.

Richey also points out the difficulty in setting priorities for the different problem pollutants or their causes based upon their different destructive powers. She presents a hypothetical example where the gradual introduction of toxic pollutants in the receiving water results in a decline of fish specie diversity and system productivity. Because the watershed has been urbanizing, increased flows have also occurred. If it is assumed that the increased flows causing flooding and scouring in the water body were the most important element restricting the fish populations, an abatement program incorporating detention facilities to reduce these flooding problems may be implemented. However, the input of toxic substances may not be reduced and significant improvements in the beneficial use may not occur. She concludes that it is very important to study all effects on a receiving body including hydrology, geomorphology, and pollutant inputs.

Scott (p.283) states that factors contributing to the instability of the physical receiving water system are relatively easy to identify but that their combined effect on the receiving water aquatic life is difficult to measure. Scott also mentions (p.55) that the Resource Planning Section of the King County Planning Division analysed available data for 15 local streams in an attempt to establish a cause and effect relationship between urban development and stream degradation. They examined watershed variables such as the magnitude of the impervious areas, peak flows, water quality, aquatic insects, and salmonid escapement to rank the streams. Bear Creek ranked third in impervious surfaces, first in peak flow, fifth in water quality, sixth in aquatic insects, and second in salmonid escapement. Kelsey Creek ranked twelfth, eighth, fifteenth, fifteenth, and eighth in the same categories indicating less desirable conditions (the higher the number, the less desirable).

The rest of this subsection presents the results of the various investigations in evaluating the effects of urban runoff on the receiving waters.

1. Bellevue Receiving Water Beneficial Uses

As described above, the first element in evaluating the effects of urban runoff is identifying the beneficial uses of the receiving waters. Kelsey Creek, the receiving water studied during this project, has three primary functions. These include: conveyance of stormwater from Bellevue to Lake Washington, providing a scenic resource for the area, and providing a habitat for fish. The most important beneficial use of Kelsey Creek is the conveyance of stormwater out of the city. The City of Bellevue, in its Storm Drainage Utility and support of projects such as these, has a commitment to provide the other beneficial uses. Richey (pp.57 and 58) states that Kelsey Creek can physically provide for all of these beneficial uses. The creek has been developed for the conveyance of stormwaters but there are also areas in its lower reaches where the canopy cover is relatively intact and the stream banks and morphology are still quite natural. Dense growth of shrubbery and blackberry vines also provide cover and shade for stream aquatic life. The riprap allows the development of deep pools which can be a good habitat for fish. Perkins (p.7 and 10) states that some of the upstream reaches and tributaries of Kelsey Creek are less disturbed and serve as a potential refuge area for aquatic life. The downstream reaches of Kelsey Creek, however, are less supportive of aquatic life due to channel instability and erosion along with flashy flows and increasing floods.

2. Bear and Kelsey Creeks Water Quality

The University of Washington project monitored Kelsey Creek and Bear Creek water quality from May, 1979, through April, 1981. Table 6 (ref. 8 Table 15 and ref. 7) summarizes these creek water quality observations. The values for the constituent concentrations (except temperature) were obtained during stable flow periods only when the creeks were not rising or falling rapidly. The constituents that were monitored were mostly in the forms that were most readily available or would have the most effect on the aquatic organisms. These include the fine particulate matter and dissolved or soluble portions of the constituents. They also periodically monitored major ions in these receiving waters (ref. 8, Table 2). The major ion types are similar for both Bear and Kelsey Creeks: calcium/magnesium bicarbonate. The concentrations of these ions were typically lower in Bear Creek. Richey (pp.73 through 91) summarized these water quality observations. She found that during the study period the average nutrient (nitrogen and phosphorus) levels in Kelsey Creek were greater than those found in Bear Creek. These enrichment factors were between 1.2 and 3.4. Total phosphorus and soluble reactive phosphorus in Kelsey Creek were about two and one-half times higher than those found in Bear Creek. The maximum concentrations of nitrogen in Bear Creek, however, were greater than those in Kelsey Creek. Nitrate plus nitrite nitrogen were about 2.4 times higher in Bear Creek while ammonia nitrogen was about 1.7 times higher in Bear Creek. She concludes that both streams have ample supplies of both nitrogen and phosphorus for the aquatic organisms. She also states that the nitrate plus nitrite concentrations had a distinct seasonal trend in Bear Creek while they were essentially random in Kelsey Creek. High winter and low summer concentrations of nitrate plus nitrite have been observed in other rural streams and are thought to be controlled largely by the seasonal nitrogen uptake of terrestrial vegetation. Bear Creek has much more riparian vegetation than does Kelsey Creek. The high nitrogen concentrations in Bear Creek may also be caused by instream nitrification. These high winter concentrations in Bear Creek resulted in high annual yields. In addition, the maximum ammonium concentrations in Bear Creek occurred during the autumn when there was decomposition of sockeye salmon bodies in the creek. The relatively high ammonium concentrations may also be a result of nitrogen mineralization.

The observed low dissolved lead concentrations in Kelsey Creek and Bear Creek are not expected to exert a major impact on the aquatic life. However, other possible toxic compounds which may be washing into the stream system were not continuously monitored. Pedersen (Chapter 4) notes that massive fish kills in Kelsey Creek or its tributaries were observed on several occasions due to the dumping of toxic materials down the storm drains. The resultant impact of this toxic material on the benthic organisms from these dumps were found to be substantial, but no permanent impact over long time periods were observed. The biochemical five-day oxygen demand concentrations were low in both streams. They found that the greatest differences in constituents between the two streams occurred in those constituents that were in particulate forms.

Table 6 Surface Water Quality (monthly average concentrations from May 1979 through April 1981)

	units	Kelsey Creek				Bear Creek				Ratio of Kelsey Creek mean values to Bear Creek mean values
		mean	SD	min.	max.	mean	SD	min.	max.	
Drainage Area	ha	3,109	-	-	-	3,600	-	-	-	0.9
Instantaneous discharge	m^3/sec	-	-	0.20(1)	8.68(2)	-	-	0.13(1)	6.31(2)	1.5 (ratio of min. values) 1.4 (ratio of max. values)
Substrate size	mm	36.7(3)	6.8	-	-	27.5(3)	4.9			1.3
Summer temperature	°C	-	-	-	23.0	-	-	-	23.0	1.0 (ratio of max. values)
Winter temperature	°C	-	-	5.0	-	-	-	3.2	-	1.6 (ratio of min. values)
Total suspended solids(6)	mg/l	11.0	7.4	2.5	32.9	4.7	3.0	0.8	11.9	2.3
Fine particulate organic carbon(6)	mg C/l	0.87	0.53	0.10	2.51	0.75	0.36	0.32	1.51	1.2
Dissolved organic carbon(6)	mg C/l	7.5	3.4	3.8	14.8	6.4	3.3	3.0	16.8	1.2
Total phosphorus(6)	µg P/l	116	32	72	193	43	16	15	79	2.7
Soluble reactive phosphorus(6)	µg P/l	82	27	54	167	24	16	8	63	3.4
Nitrate plus nitrite N(6)	µg N/l	743	137	468	962	508	540	59	2,350	1.5
Ammonium N(6)	µg N/l	36	14	12	66	30	26	9	114	1.2
Biochemical oxygen demand(4)(6)	mg O_2/l	2.26	1.27	0.86	5.3	1.63	1.08	0.03	3.59	1.4
Exchangeable lead(5)(6)	µg Pb/l	5	2	2	11	<4	-	<4	<4	>1.3

Sources: Richey (ref. 8, table 15) and Richey, Perkins, and Malueg (ref.7).

(1) July 1979
(2) December 1979
(3) median
(4) 5-day demand, samples from May 1979 through December 1980 only.
(5) Samples from May 1979 through September 1980 only.
(6) Stable flow values only - creeks were not rising or falling rapidly.

Scott (pp.54 and 56) summarizes these water quality observations:

o Kelsey Creek had higher nutrient concentrations than Bear Creek;

o Kelsey Creek had one to two times the suspended particulate loads of Bear Creek;

o Inorganic silt was the dominant fraction of the suspended particulate load in Kelsey Creek; and

o The concentrations of potentially toxic materials in both study streams were quite low and possibly negligible.

Observed problems in Kelsey Creek included high water temperatures and elevated fecal coliform populations. The fecal coliform populations, however, varied considerably throughout the Kelsey Creek drainage system. Bear Creek also had high fecal coliform populations along with high inorganic nitrogen and total phosphorus concentrations.

The annual creek discharges of various water quality constituents are shown in Table 7 (ref. 7, Table 16). Richey summarizes the constituent transport (pp. 85 through 93). The total solids concentrations were highest during the periods of high flows (late fall, winter, and early spring). Therefore, most of the solid material was transported during only a few months of the year. Thirty-three percent of the solids were transported out of Kelsey Creek and 35 percent out of Bear Creek during the high flow month of December alone. The annual yields of both particulate and soluble phosphorus were about three times greater in Kelsey Creek than in Bear Creek. The total suspended solids transport in Kelsey Creek was almost four times greater than Bear Creek. While the fine particulate organic matter in Kelsey Creek was almost three times more than in Bear Creek on an annual basis, the dissolved organic carbon transport was about the same. High phosphorus concentrations in the fall in Bear Creek may also be caused by decomposing sockeye salmon. Scott reported more than 1000 sockeye carcasses in the stream channel during the fall of 1979 and 1980.

Suspended solids concentrations were observed during several different storm events in both creeks (ref. 8, p.91 through 93). Kelsey Creek was found to have significantly higher mean concentrations of suspended solids than Bear Creek during these events. The amount of inorganic silt found in the suspended solids load of the urban stream was much greater than in Bear Creek. In addition, the observed suspended solids concentrations in Bear and Kelsey Creeks increased by about an order of magnitude compared to base flow conditions. Differences in concentrations along the two streams were observed in Bear Creek but the concentrations were more consistent in Kelsey Creek along its channel length. The base flow concentrations of suspended solids were about two to three times greater during both base flow and peak flow conditions in Kelsey Creek than in Bear Creek. The base flow suspended concentration in Kelsey Creek was about 14 mg/L while it was only about six mg/L in Bear Creek. During peak flow conditions these concentrations increased by about eight times in both creeks. The peak flow concentrations in Kelsey Creek were about 110 mg/L while they were about 50 mg/L in Bear Creek.

The base flow rates observed in Kelsey Creek were about 800 liters/second while they were about 1200 liters/second in Bear Creek. The peak flows were

Table 7 Annual Creek Discharges for June 1979 through May 1980 (kg/ha/yr)

Constituent	Kelsey Creek	Bear Creek	Ratio of Kelsey to Bear Creek Discharge
Total suspended solids	300	78	3.8
Fine particulate organic carbon	33	12	2.8
Dissolved organic carbon	53	55	1.0
Soluble reactive phosphorus	0.56	0.17	3.3
Total phosphorus	0.87	0.33	2.6
Nitrate plus nitrite nitrogen	4.3	7.1	0.6

Source: Richey (ref. 7, table 16)

about 4300 liters/second in Kelsey Creek, and about 2700 liters/second in Bear Creek during the few storms that were monitored. Therefore, the total difference in solids transport in Kelsey Creek between base and peak flows was about five, while it only increased by about two times in Bear Creek.

Richey (pp.121 and 122) states that Kelsey Creek is surprisingly clean for a heavily urbanized stream. This might be because of the instream dilution of the contaminants, because some of the watershed is still relatively protected, or possibly the result of differences in the occurrence of the urban contaminants. She further states that Kelsey Creek is enriched but does not appear to be polluted in the classic sense of the word. The rapid transport of water and materials appears to protect the stream by removing many of the potentially hazardous pollutants downstream. The toxic contaminants that are present appear to have minimal effects on the indigenous population of at least algae. In addition, the rapid transport of water also helps to maintain high levels of dissolved oxygen.

The City of Bellevue project (ref. 5, pp.2-2 to 2-3 and 6-18 to 6-19) evaluated water quality with beneficial use criteria. The urban hydraulic conditions in Bellevue allow the observed runoff water quality to be compared to the beneficial use receiving water quality. Typically, urban runoff should not be compared to water quality criteria because the published criteria were established for continuous conditions, while urban runoff is considered a slug discharge. However, the base flow and urban runoff qualities in Bellevue do not differ greatly. Therefore, as an approximation to identify potential problem pollutants, the beneficial use water quality criteria for aquatic life published by EPA was compared with the observed Bellevue runoff water quality. It was found that direct receiving water effects from urban runoff may not be significant for most rain events (except possibly for ammonium and nitrate nitrogen). Identified potential long term problem pollutants are settleable solids, lead, and zinc. These materials may settle out in the stream sediments possibly causing long term problems. These long term problems are caused by settled organic and inorganic debris and particulates. This material may silt up salmon spawning beds in the Bellevue streams and introduce high concentrations of potentially toxic materials directly to the sediments. Oxygen depletion caused by organic sediments may also occur under certain conditions, and the lead and zinc concentrations in the sediments may affect the benthic organisms. The discharge of particulate heavy metals which settle out in the sediments may be converted to more soluble forms through chemical or biological mechanisms. The other subsections in this discussion address specific interstitial water quality effects from sedimentation and observed problems associated with specific aquatic life organisms.

3. Creek Interstitial Water Quality

The University of Washington project and the Seattle METRO project analysed interstitial water for various constituents. These samples were obtained by inserting perforated aluminum stand pipes into the creek sediment. These samples therefore represent the water flowing between the sediment particles. This water is therefore most affected by the sediment quality and affects in turn the benthic organisms much more than the creek water column.

Scott, et al, (pp. 271 and 272) state that the interstitial water pH values ranged from 6.5 to 7.6 and did not significantly differ between the streams but did tend to decrease during the spring months. The lower fall temperatures and pH levels contributed to reductions in ammonium (ionized ammonia) concentrations. The total ammonia and ammonium concentrations were significantly greater in Kelsey Creek than in Bear Creek. They also found that the interstitial dissolved oxygen concentrations in Kelsey Creek were much below those concentrations considered normal for undisturbed watersheds. These decreased interstitial oxygen concentrations were much less than the water column concentrations and indicated the possible impact of urban development. The dissolved oxygen concentrations in the interstitial waters and Bear Creek were also lower than expected potentially suggesting deteriorating fish spawning conditions. During the winter and spring months, the interstitial oxygen concentrations appeared to be intermediate between those characteristic of disturbed and undisturbed watersheds.

The University of Washington (ref. 8, pp.102-104) also analysed heavy metals in the interstitial waters. They found that copper and chromium concentrations were very low or undetectable while lead and zinc were higher. Kelsey Creek interstitial water also had concentrations approximately twice those found in the Bear Creek interstitial water. They expect that most of the metals were loosely bound to fine sediment particles. Most of the lead found was associated with the particulates and very little soluble lead was found in the interstitial waters. The interstitial samples taken from the stand pipes were full of sediment particles which could be expected to release lead into solution following the mild acid digestion for exchangeable lead analyses. They also found that the metal concentrations in Kelsey Creek interstitial water decreased in a downstream direction. They felt that this might be caused by stream scouring of the benthic material in that part of the creek. As described later in this section the downstream Kelsey Creek sites were more prone to erosion and channel scouring while the most upstream station was relatively stable.

Seattle METRO (ref. 2, Tables 61 and 62) also monitored heavy metals in the interstitial waters in Kelsey and Bear Creeks. Table 8 summarizes these total heavy metal concentrations observed. In many cases the winter Bear Creek interstitial water quality was worse than the Kelsey Creek samples at the same time. These data are based on only a few samples (three interstitial water samples during the winter season in both Kelsey and Bear Creeks, and only one sample during the dry season). The EPA's fresh water criteria for mostly dissolved metallic forms are also shown in this table. Other metals analysed but found in low concentrations include antimony (less than three ug/L), mercury (less than one ug/L), selenium (less than three ug/L), silver (two Kelsey Creek samples had silver concentrations of 13 and 0.6 ug/L while the other samples analysed had less than 0.5 ug/L), and cyanides (all samples had concentrations of less than or equal to ten ug/L). Care must be taken when comparing the water quality criteria shown in Table 4 with these observed interstitial water concentrations. Most of these criteria were calculated using an appropriate hardness value of 20 mg/L. During dry weather conditions, the hardness would typically be higher than during periods of storm runoff. The chronic criteria is not supposed to be exceeded during a 24-hour average while the acute criteria is a maximum and should never be exceeded. Usually only the heavy metals in soluble or ionic form are considered toxic to aquatic organisms. However, when the total metal concentrations are considered, then conservative evaluations are possible as instream chemical and biological mechanisms may convert the metallic forms into dissolved forms. METRO (ref. 2, p.3-99) found large variations in heavy metal concentrations at the same site after repeated sampling (as much as 200 times different), depending upon

Table 8 SEASONAL DIFFERENCES IN INTERSTITIAL STREAMWATER METALS (µg/ l)

Total Metal	Kelsey Creek (Urban Stream)		Bear Creek (Rural Stream)		EPA Freshwater Criteria for dissolved metalic forms	
	winter (wet) season mean (sd)^a	summer season^b (dry)	winter season^b (wet)	summer season^b (dry)	acute	chronic
Arsenic	35 (±9)	3	46	4	440(2)	NA
Beryllium	0.4 (±.1)	< 0.3	0.5	<0.1	NA	NA
Cadmium	1.1 (±.4)	<0.1	3.6	0.2	0.6(1)	0.005(1)
Chromium	42 (±3)	4	78	1	NA	NA
Copper	77 (±20)	5	230	2.4	5.0(1)(3	5.6(3)
Lead	210 (±52)	<1	120	1	24(1)(3)	0.09(1)(3
Nickel	22 (±4)	<6	27	< 7	540(1)(3	28(1)(3)
Zinc	240 (±40)	13	460	12	85(1)(3)	47(3)

^{a}n=3 ^{b}n=1

Source: Galvin and Moore (ref. 2, table 61 and 62)

(1) Criteria estimated using a water hardness of 20 mg/l.
(2) For trivalent arsenic only.
(3) For total metal forms.

whether the sample was obtained during the wet or the dry season. Both Kelsey and Bear Creeks had much higher concentrations during the high runoff periods as shown in Table 8. Because the interstitial water samples had high concentrations of suspended materials, they felt that these samples were not completely representative of the available metal forms. The high interstitial water metal concentrations were similar to the stormwater runoff metal concentrations as reported in Section B of this report. It was found that almost all of the lead was associated with particulate matter. Because many of the heavy metals in the interstitial water was associated with very fine particles, these are flushed rapidly through the stream during high stormwater flow periods. During storm periods, the interstitial water and creek water heavy metal concentrations approached the stormwater values (200 ug/L for lead). During non-storm periods, the interstitial lead concentrations were typically only about 1 ug/L.

METRO (ref. 2, p.3-98 through 101) also analysed priority pollutant organics in interstitial waters. Only benzene was found and only in the urban stream. The observed benzene concentrations in two Kelsey Creek samples were 22 and 24 ug/L while the reported concentrations were less than one ug/L in all other interstitial water samples analysed for benzene.

Cadmium exceeded the acute criteria for four of the six interstitial water quality samples obtained, and exceeded the chronic criteria by very large amounts in all but one sample. The wet season copper concentrations observed were greater than either the acute or the chronic criteria in both creeks. The high wet season lead and zinc concentrations also exceeded both the acute and the chronic criteria.

4. Increased Kelsey Creek Water Flows

The increasing population of the City of Bellevue and the observed peak annual discharges have been studied by the University of Washington (ref. 8, pp.40 through 53). Bellevue was initially settled in 1883 but it grew slowly, reaching a population of only 400 by 1900. Bellevue was mostly used as logging but farming was more important by the early 1900's. The Bellevue population density continued to be low until the 1940's. During this time almost the entire Kelsey Creek drainage basin was undeveloped. In the late 1940's, the City of Bellevue's population was stimulated by the construction of the Lake Washington floating bridge connecting Bellevue to Seattle and in 1949 the bridge tolls were abolished. From 1950 to 1970 low density residential housing progressed rapidly and the population of the greater Bellevue area increased by nearly 600 percent. By 1959, residential housing occupied a substantial portion of the Kelsey Creek watershed. The Bellevue population slowed during the 1970's due to the depressed local economy and the saturation of land development. In 1976, the population of the City of Bellevue was estimated to be 67,000 people. Figure 2 is a plot showing the increase of Bellevue population by decade along with the observed peak annual discharges in Kelsey Creek from the mid-1950's. It seems that the peak annual discharges almost doubled between the 1950's and the late 1970's. The frequency of flooding during this period of time has also increased. Floods that used to return every ten years can now be expected to return at least every other year. An earlier study attempted to identify and measure the environmental response of streams to urban development within the Bellevue watershed. This earlier study concluded that the total volume of runoff expressed as a monthly average had increased only slightly in Kelsey Creek over pre-urbanized years, but that flood peaks had increased two to three

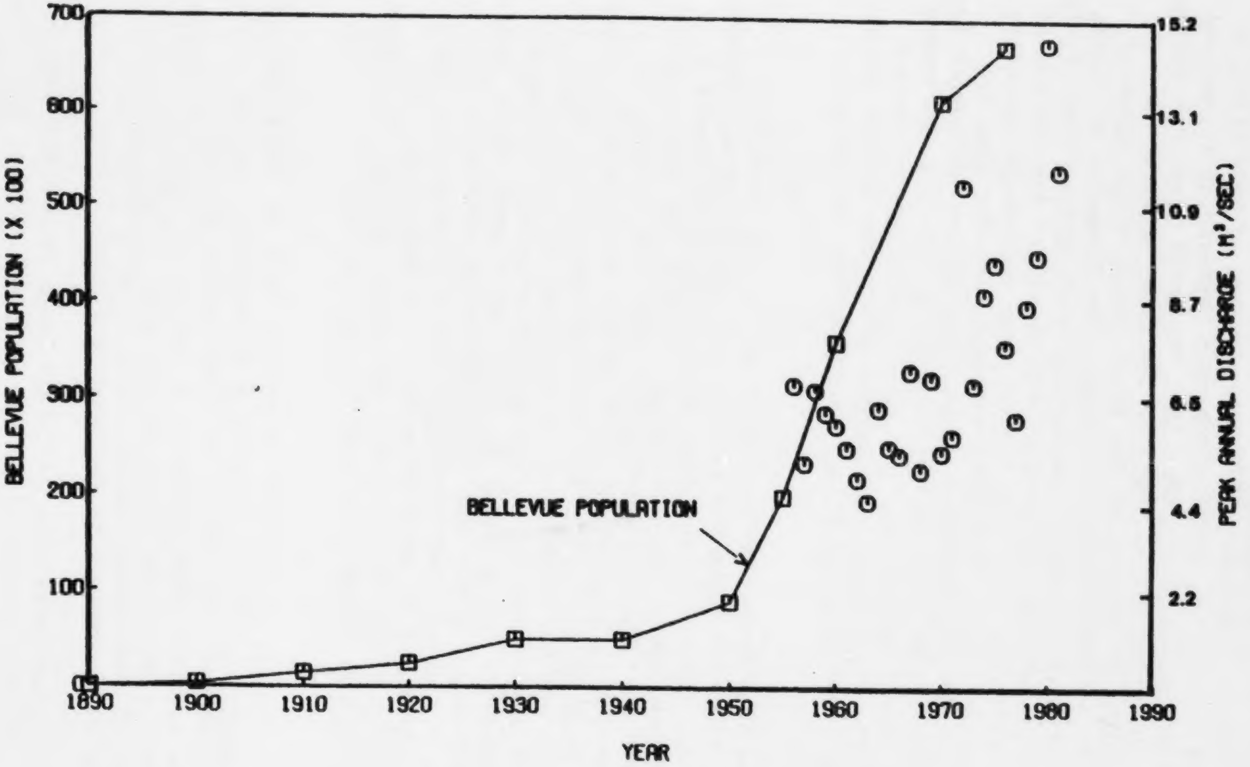


Figure 2 Population of Bellevue and peak annual discharge in Kelsey Creek (ʘ). Data from U.S.G.S. and Bellevue Planning Dept. 1977.

Source: Scott, Steward, and Stober (ref. 9, figure 7).

times over the same period. The increase in intensity of runoff has had a measurable effect on the channel stability in Kelsey Creek.

The University of Washington in conjunction with the USGS monitored the flows in Kelsey and Bear Creeks from June, 1979, through May of 1980 (refs. 4 and 7). Table 9 summarizes the monthly total discharges observed in Kelsey and Bear Creeks during this time period. It is seen that the total watershed yields were nearly identical in these two basins. Most of the flows occurred in December of 1979 and less than 25 percent of the total annual flows occurred from June through November. As noted earlier, however, the frequency of floods and the observed high flows have increased substantially in recent times. Table 10 summarizes the recurrence interval of various peak flows for the periods of 1962 to 1970 and 1971 to 1980. The peak flow for the same recurrence intervals have approximately doubled for those recurrence intervals greater than two years. During the early period a discharge of seven cubic meters per second had a ten-year recurrence interval while it had only a one- to two-year recurrence interval during the more recent period. Also, a 100-year recurrence interval storm had a peak flow of 8.4 cubic meters per second during the earlier period and was almost doubled to 16.7 cubic meters per second during the latter period.

The response of the two streams during individual storms were also significantly different. Figure 3 shows how Kelsey Creek responded much more to two storms than Bear Creek. The hydrograph rise and fall occurred within a matter of hours during a rain event. The downstream flooding and the rapid transport of dissolved and particulate materials was therefore greater in Kelsey Creek than in Bear Creek. Because the total annual runoff yields in both watersheds are similar, much more of the total runoff occurs during storms in Kelsey than in Bear Creek. The variation in flows would be much less in Bear Creek. The peak flows occurred primarily during the winter months (November through March). The response of Kelsey Creek to these two example rains showed a very rapidly rising hydrograph while Bear Creek responded relatively slowly. After peaking, the flows in Kelsey Creek typically return to base flow rates in less than 24 hours while 48 hours or more was required in Bear Creek. The maximum annual discharges in Kelsey Creek during the steady period was almost 60 percent greater than in Bear Creek (4.6 liters/hectare versus 1.9 liters/hectare).

Because of these increased flows, much of Kelsey Creek is characterized by unstable banks with much erosion and deposition of sediment. Storage sites along the channel are infrequent and the Kelsey Creek stream channel is narrower and deeper than expected when compared to typical undisturbed streams serving similar watersheds. The Kelsey Creek surface area at bank-full conditions is about half of Bear Creek. Kelsey Creek is quite changed in hydrology and morphology when compared to the more rural Bear Creek.

The amount of stream power available in Kelsey Creek is greater than in Bear Creek despite the slightly greater slope of Bear Creek. During peak flows, Kelsey Creek has more than twice the available power as Bear Creek. Kelsey Creek can therefore move and erode sediments much more effectively than Bear Creek.

Richey (pp.29 through 33) also summarizes low flows observed in Kelsey and Bear Creeks during this period of study. The differences in low flow conditions were significant (greater than 98 percent significant that the unit area low

Table 9

Monthly Discharge

Water Year June 1979 - May 1980

Month	Kelsey Creek		Bear Creek	
	Discharge ($10^6 m^3$/month)	Percent of annual total	Discharge ($10^6 m^3$/month)	Percent of Annual total
June 1979	0.6	3	0.6	3
July	0.8	4	0.6	2
August	0.7	3	0.6	2
September	1.0	4	0.5	2
October	1.6	7	0.9	4
November	1.0	4	0.8	4
December	5.1	23	5.5	23
January 1980	3.0	13	3.7	16
February	3.2	14	3.2	14
March	2.3	10	3.7	16
April	2.0	9	2.4	10
May	1.3	6	1.1	5
Annual Total	23		24	

annual average unit area runoff (m^3/ha): 7,160 Kelsey Creek
7,010 Bear Creek

Source: Richey (ref. 8, table 17)

Table 10

Flood Frequency Estimates, Kelsey Creek

Recurrence Interval (yr)	1962-70 (m^3/s)	1971-80 (m^3/s)
1.01	3.68	4.33
1.25	4.79	6.68
2.	6.63	11.36
5.	6.43	10.85
10	6.97	12.32
25	7.56	14.13
50	7.99	15.41
100	8.38	16.68

Source: Richey (ref. 8, table 5).

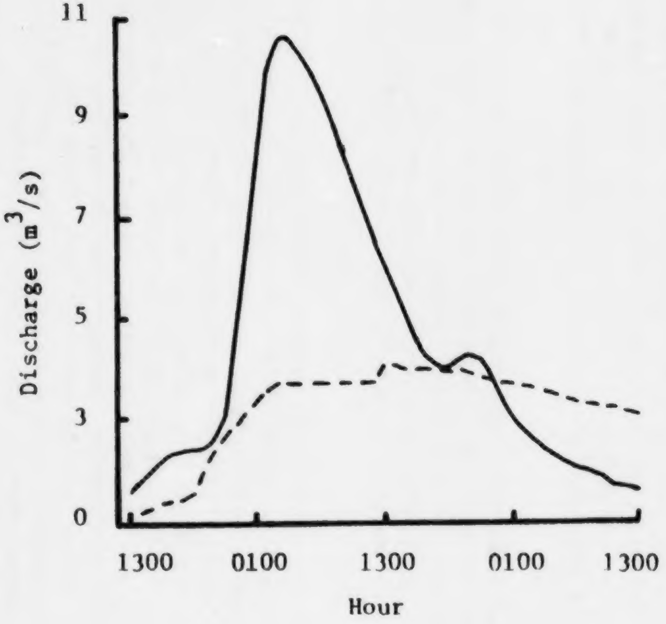


Figure 3a . Hydrographs during a winter storm (m^3/s), December 14-16, 1979 (—— = Kelsey Creek, - - - = Bear Creek)

Source: Richey (ref. 8, figure 6).

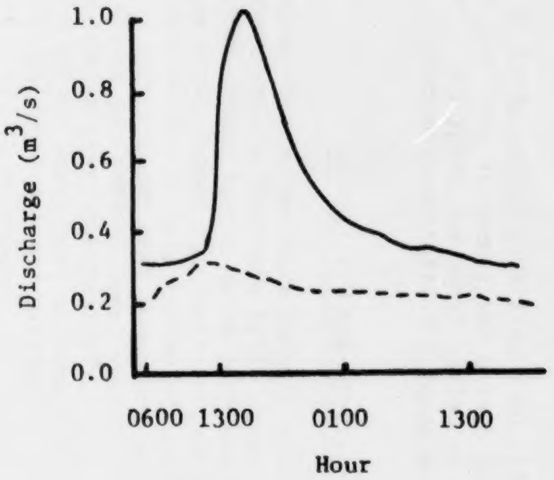


Figure 3b . Hydrographs during a summer storm (m^3/s), July 12-13, 1979 (—— = Kelsey Creek, --- = Bear Creek) flow discharges were not equal). On a unit area basis, about 30 percent more water was flowing in Bear Creek during the summer of 1981 than in Kelsey Creek. The low flow summer discharge in Kelsey Creek was about 250 liters/hour/hectare while the Bear Creek flows were about 350 liter/hour/hectare.

5. Aquatic Organism Food Availability and Utilization

The University of Washington studies examined primary productivity and the availability of food. Richey (pp.151-154) examined primary productivity in both Kelsey and Bear Creeks. She found that on an annual basis, primary productivity per unit area (measured as carbon fixation) was almost twice as large in Kelsey Creek (56 grams of carbon per square meter) than it was in Bear Creek (34 grams of carbon per square meter). She concluded that the scouring of the biomass during periods of high flows in Kelsey Creek limited the amount of primary production even though there were sufficient nutrients available. The low levels of primary productivity measured in Bear Creek during October may have been the result of high turbidity limiting the infiltration of sunlight in the water. Richey (p.177) also examined the consumption of large organic material by grazing macroinvertebrates and microbes. The loss of leaf litter in both streams occurred at approximately equal rates. The causes for the loss of the leaf litter, however, was quite different. The microbial degradation and consumption by leaf shredding organisms are more important in Bear Creek while downstream transport of the leaf material in Kelsey Creek was most important. There was some macroinvertebrate consumption of leaf material in some of the Kelsey Creek locations but this consumption occurred at a slower rate than in Bear Creek.

Richey (pp.180-181) also conducted experiments examining the toxicity of the periphyton in Kelsey Creek to mayflies. The mayflies, even though absent in Kelsey Creek, consumed the periphyton from both streams with equal efficiency and speed. The adults emerged successfully in equal numbers and the surviving larvae were indistinguishable in terms of activity levels from both Kelsey and Bear Creek periphyton.

The University of Washington's projects also examined the availability and quality of particulate organic matter as food in both creeks. Particulate organic matter (POM) was defined as all organic matter that accumulated on the surfaces of rocks larger than one millimeter in diameter. Food quality was defined as the ratio of POM divided by fine silts and as carbohydrate content per gram of POM. (ref. 7, p.812). They found no differences in the amount of particulate organic matter measured in the two creeks (about 100 grams/square meter). There was a significant difference, however, in its quality as food for higher trophic levels and the timing of its availability. There was significantly more particulate organic matter in Kelsey Creek during August and significantly less during November than in Bear Creek. The surface accumulations of material in Kelsey Creek had much more fine silts associated with them and had a lower carbohydrate content. They also analysed the protein content of a particulate organic matter but with varying results.

The transport of fine particulate organic matter (FPOC) in Bear Creek was only 37 percent of Kelsey Creek's export. This could be due to the storage of fine material in Bear Creek while this material was flushed in the higher flows from Kelsey Creek. Most of the FPOC export occurred in Bear Creek during

December while most of the export in Kelsey Creek occurred in October. In Kelsey Creek, small discharges during early fall had enough power to transport large quantities of fine materials. Even though large storms occurred in December, most of the fine materials had already been removed. The discharges and associated stream power in Bear Creek did not become large enough to transport significant quantities of FPOC until later in the year. The storage of FPOC in Bear Creek during the fall months is important for many macroinvertebrates. The lack of FPOC in Kelsey Creek during this time period may be the cause for the limited survival of certain macroinvertebrates.

As mentioned earlier, primary productivity in the creeks contributed small fractions of the total carbon input of both streams (less than one percent). Also, the primary productivity in Bear Creek may have been limited by less sunlight penetrating the water.

Richey (p.196) found that more of the particulates in Kelsey Creek were associated with the fine particulate organic carbon fraction than in Bear Creek. A great deal of the fine material appeared to be carried directly from the watershed in the storm drainage system. In the rural stream, there was a greater interception of fine materials prior to entrance into the stream channel. The storage of FPOC within upstream and tributary reaches appears to be almost nonexistent in Kelsey Creek while such storage behind debris dams and along flood plains is a typical feature in natural stream systems and helps to provide sites for feeding activity. Much of the FPOC that entered Kelsey Creek was not available to the biota in the stream system since it moved through it so rapidly. The observed decreased species diversity observed in Kelsey Creek at the higher trophic levels as discussed in later subsections may be in part directly caused by differences in the quality and temporal availability of the primary food source (FPOC).

Pedersen (pp.85 through 92) discusses the effects of the particulate organic matter on the benthic invertebrate population. Kelsey Creek lacked many of the organisms that could utilize a large percentage of the large particulate organic matter (LPOM). Many of these organisms were found in Kelsey Creek in isolated locations, however. They can rapidly expand their populations which implies a potential for the recovery of Kelsey Creek. Richey (pp.199-203) states that even though there is evidence of reduced quality of food in Kelsey Creek, this may not be a limiting factor. The absence of filtering organisms in Kelsey Creek, such as the clam populations observed in Bear Creek, indicate that food quality may have had some influence on the types of organisms found in the stream. The available food in Kelsey Creek was not acutely toxic to organisms in the urban stream. The transport mechanisms in Kelsey Creek, however, resulted in very little contact of the stream bed with the available organic material. The organisms that are found in Kelsey Creek are quite adaptive to unpredictable changes in both food quantity, quality, and water quality.

Refuge areas seem to play an important role in Kelsey Creek. The more stable areas in Kelsey creek had aquatic life populations comparable to those found in Bear Creek. These refuge areas did not balance the lack of diversity observed in Kelsey Creek. The Kelsey Creek biota are relatively inefficient in utilizing the food resources available. The efficiency of utilization was only three percent in Kelsey Creek and about 20 percent in Bear Creek when the throughput of dissolved organic carbon was excluded (ref. 4, pp.18-21).

6. Riparian Vegetation

Richey (p.44) states that modifications to the vegetative cover have been very significant in Kelsey Creek. The riparian vegetation was relatively intact throughout the entire length of Bear Creek, while only the upper 800 meters of Kelsey Creek had a significant amount of intact riparian vegetation. Most of the riparian vegetation along Kelsey Creek was new growth alders less than 150 mm in diameter, vine maple, and blackberry vines. The riparian vegetation along most of Bear Creek was old growth fir, cedar, and alder which are greater than 300 mm in diameter with an understory of salmonberry and vine maple. Riparian cover in the stream channel in both streams was common, however. Many sections of Kelsey Creek were overhung with dense blackberry vines which did provide some shade and instream cover.

Pedersen (p.89) states that the vegetation along each watershed was possibly the major factor affecting species composition. Usually a reduction in riparian vegetation causes an increase in water temperature which could cause faster insect growth. The differences in food quality, however, outweigh the direct effects of temperature on most larval growths.

Scott, Steward, and Stober (pp.286-287) state that the most beneficial effect of stream alteration is the increase in solar energy reaching the stream surface as the result of the removal of a significant portion of the overhanging canopy. The current riparian vegetation along the middle and lower reaches of Kelsey Creek are only a small fraction of its former growth. The removal of this stream side cover, however, has not resulted in excessive water temperatures and appears to have indirectly benefited the trout populations in the urban stream. Bear Creek, which is heavily canopied along most of its length, can be considered light-limited. Maximum fish growth in Bear Creek occurs in the fall months after leaf fall when sunlight can reach the water. This is different from Kelsey Creek where the fish growth is stimulated during the spring and early summer months when the periphyton and probably the benthic productions are greatest. Regardless of the relative production of the benthic invertebrates in each stream, it was found that the salmonids grew more rapidly in Kelsey Creek than in Bear Creek. The size of an age I migrant cutthroat trout from Kelsey Creek was near the length of age II out migrants from Bear Creek.

7. Algae

University of Washington studies (ref. 7) found that periphyton algae were the most predominant ingredient in the organic accumulation of material in Kelsey Creek. Algae was not nearly as important in Bear Creek. Richey (pp.111-119) conducted some algae potential bioassays with interstitial water, stormwater, and direct runoff water from the urban stream and its watershed. Only very low levels of inhibition to growth were found and there were few instances where there were growth differences from samples taken from the two different streams. However, she does point out that the test waters were not the most heavily polluted that can occur in the system. These tests did indicate that the particulate bound metals were mostly not available to the algae. She found that the stream interstitial water caused slight growth inhibition during the laboratory algal tests but that the indigenous algal cells were much less affected. Similar results were found with the stormwater and the runoff waters. She concludes that there is a potential for toxic impact of the stormwaters on the algae in Kelsey Creek. It did not appear to be a dominant factor in limiting algae survival.

8. Benthic Organisms

Scott, Steward, and Stober (p.55) note an earlier study that examined Bear and Kelsey Creeks along with several other creeks in the Seattle area. This earlier study rated the quality of the benthic macroinvertebrate populations in these streams. Four parameters were indexed including the mean total number, the mean total volume, the number of taxonomic groups, and the percentage composition of Ephemeroptera, Plecoptera, and Trichoptera insect taxa. Kelsey Creek was judged to be poor in quality and to rank lower in all of the index parameters than did Bear Creek which was considered to be of fair quality .

Pedersen examined the benthic organisms in Kelsey and Bear Creeks as part of the University of Washington's project. He studied the relative occurrence of these bottom organisms in the two streams from about 350 samples. Table 11 summarizes the relative occurrence of the different benthic macroinvertebrates in Kelsey and Bear Creeks. The difference in the variety of the organisms found was striking. Insects such as mayflies, stoneflies, caddisflies, and beetles were observed only rarely in Kelsey Creek and were usually of the same few families. Baetids, however, were found in large numbers in certain regions of Kelsey Creek (relatively undisturbed channel sections with riparian vegetation intact). Bear Creek demonstrated a much more diverse distribution of benthic organisms and usually showed more than one dominant family in each major grouping. Figure 4 summarizes the occurrence of these major benthic organism groupings in these two creeks during the period of study.

The overall abundance of benthic organisms based on the average number of organisms per sample were not significantly different in Kelsey and Bear Creeks. Kelsey Creek had a mean abundance of about 53 organisms per sample while Bear Creek had a value of about 48. A total of 179 samples were obtained at Kelsey Creek while 127 samples were obtained from Bear Creek.

The worm category in Kelsey Creek was dominated by oligochaets which represented about 50 percent of benthic biota in Kelsey Creek. Amphipods and occasional crayfish made up about 36 percent of the total benthos population. In Bear Creek, the worm category only counted for about 12 percent of the total benthos while the amphipod and crayfish group accounted for less than 15 percent of the total. Chironomids showed up at about ten percent in Kelsey Creek demonstrating a fairly stable population over time except in late July when the population jumped to nearly 30 percent of the total benthos. The chironomids in Bear Creek made up closer to 20 percent of the total benthos population. In summary, the benthic life forms dominating Kelsey Creek were of the collector-gatherer feeding types which have a greater potential to survive in disturbed systems. The information presented in Figure 4 after late September is probably not accurate because of the very high discharges from storms that occurred in October which severely disturbed the stream beds and made efficient sampling difficult.

Figure 4 shows the fluctuating composition of the benthos populations with time. The benthos in Kelsey Creek generally showed a constantly changing composition with large variations in total numbers while the composition in

Table 11. Occurrence of Benthic Macroinvertebrates
In the Study Streams

Key: + abundant; - common; 0 no observed occurence

	Relative Occurence	
	Bear Creek	Kelsey Creek
Ephemeroptera		
Leptophlebiidae	+	0
Baetidae	+	+
Heptageniidae	-	0
Siphlonuridae	-	0
Ephemerellidae	-	0
Ephemerella		
Plecoptera		
Nemouridae	+	-
Leuctridae	+	0
Chloroperlidae	-	0
Perlodidae	-	0
Isogenus		
Isoperla		
Trichoptera		
Rhyacophilidae	+	-
Psychomyiidae	-	-
Polycentropodidae	-	0
Branchycentridae	-	0
Limnephilidae	-	0
Hydroptilidae	-	0
Hydropsychidae	+	-
Parapsyche		
Leptoferlidae	-	0
Oecetis		
Coleoptera		
Elmidae	+	0
Dryopidae	-	-
Noteridae	-	0
Limnichidae	-	0
Dytiscidae	-	0
Hydracarina		
Limnocharidae	-	-
Sperchonidae	-	0
Pionidae	-	0
Hygrobatidae	-	0
Athienemanniidae	-	0
Arrenuridae	-	0
Lebertiidae	-	-
Crustacea		
Decopoda	+	-
Isopoda	-	-
Amphipoda	+	+
Gammarus		
Diptera		
Chironomidae*	+	+
Orthocladiinae (Predominate group in both streams with a generic breakdown as shown: P present, A absent)		
Synorthocladius	P	P
cf. *semiverens*		
Brillia sp.	P	P
Cricotopus sp.	P	A
Parametriocnemus	P	A
cf. *lundbecki*		
Nanocladius sp.	P	A
Thienemanniella sp.	P	P
Corynoneura sp.	P	P
Orthocladius sp.	P	P
Eukiefferiella		
cf. *coerulescens*		
cf. *calvescens*		
Ceratopogonidae	-	-
Tipulidae	-	-
Culicidae	-	-
Heleidae	-	-
Epididae	-	-
Simuliidae	-	0
Dixidae	-	0
Mollusca		
Gastropoda		
Ferrissia	+	+
Planorbidae	-	-
Pelecopoda		
Pisidium	-	+
Sphaerium	-	0
Eupera	0	-
Annelida		
Oligochaeta	+	+
Nematoda	-	-
Hirudina	-	-
Turbellaria		
Planaria	-	-
Cnidaria		
Hydra	0	-

*identification by Steven White, University of Washington, College of Fisheries

Source: Pedersen (ref. 3, Table 2)

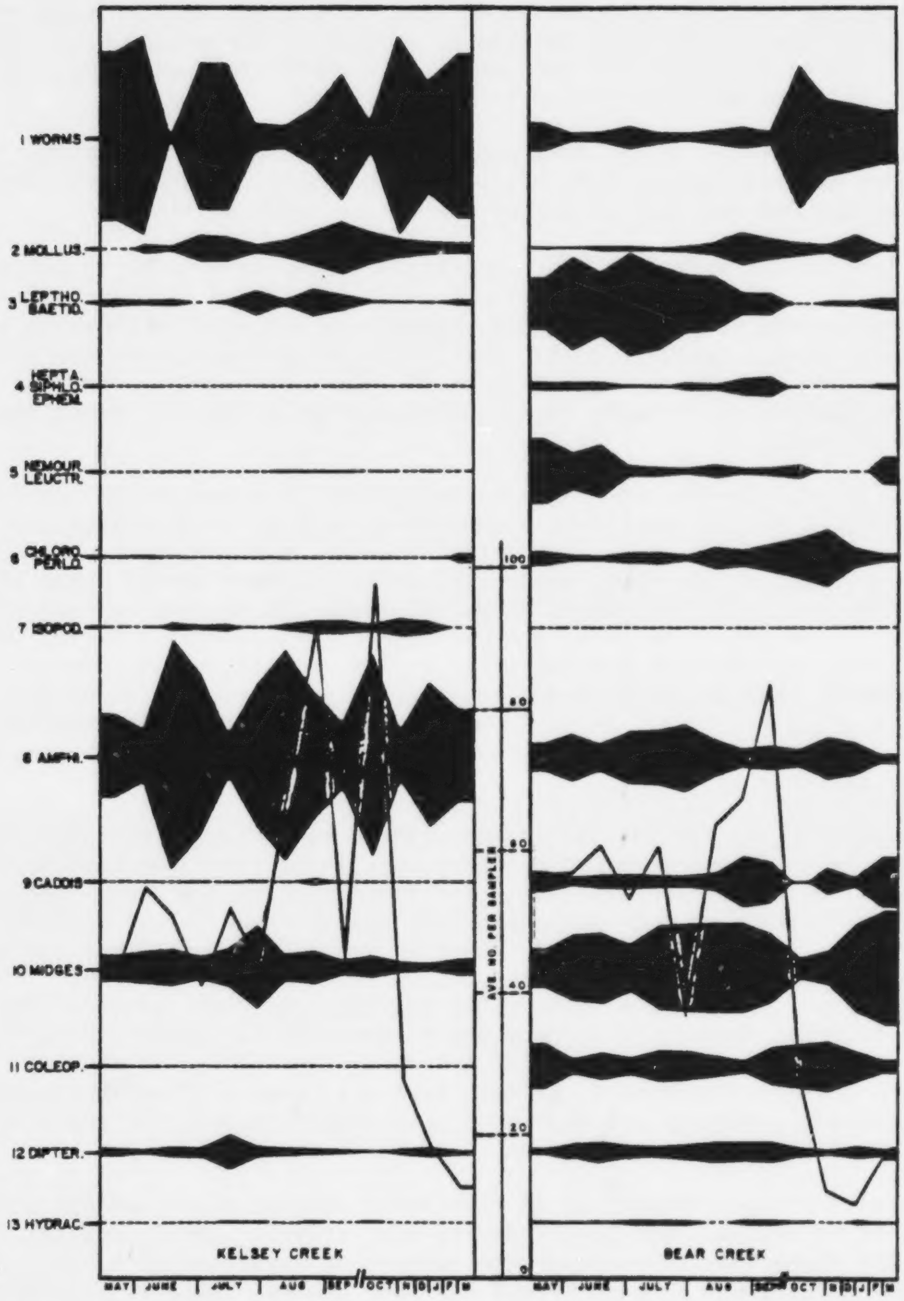


Figure 4. Percent composition and abundance (average number per sampler) of macroinvertebrates sampled in Kelsey and Bear Creeks, May 1979 to March 1980. See Table 3 for

Source: Pedersen (ref. 4, figure 4).

Bear Creek did not change so much. The Bear Creek benthic organisms were also much more evenly distributed among the different taxa. The calculated Shannon-Weiner diversity index (H) ranged from 0.65 to 2.72 in Kelsey Creek and from 2.6 to 3.78 in Bear Creek. Typical diversity values of less than or equal to one typically indicate polluted conditions, and values greater than three indicate unpolluted conditions. Therefore, several of the Kelsey Creek stations can be considered polluted with some marginally unpolluted, while most of the Bear Creek stations were considered to be unpolluted.

Statistical tests showed that each of the stations did not follow the same pattern of invertebrate life histories. The cyclic nature of the benthic populations was not the same at all of the Kelsey Creek stations.

The lack of the different representatives of the herbivores in Kelsey Creek (such as stoneflies or caddisflies) which were found in Bear Creek was probably due to the sensitive nature of Nemouridae and most trichoptera to environmental stress (ref. 3, p.80). Mayflies such as the Baetids are more adaptable to minor disturbances. The lack of other herbivores could have allowed the Baetids to increase their numbers due to a lack of competition and lack of predators.

The violent flows and increased sedimentation in Kelsey Creek could be a problem for most benthic organisms except those such as oligochaetes and chironomids which are burrowers and filter feeders, and amphipods, which can burrow or swim and filter feed. Generally, filter feeders prefer areas of little sediment accumulation where they are exposed to maximum current. The fact the chironomides maintain relatively stable populations in Kelsey Creek through storms and possible extreme water quality conditions as compared to other groups of insects could be due to their relatively short generation time and high recovery potential. Not all chironomids or oligochaetes, however, are limited to strictly polluted conditions; they can have dense populations where other insects are also found.

Pedersen (pp. 82 and 83) states that it may be difficult to understand how amphipods were so dominant in Kelsey Creek when these creatures have been described in the older literature as being indicative of high water quality. Amphipods are capable of both suspension and deposit type filter feeding. Benthic deposit feeders ingest food materials found on the sediment surface or within the sediment, while benthic suspension feeders remove the food from the overlaying water. Higher water velocities increase the flows of suspended materials favoring suspension feeders while removing the fine grain particulate matter from the sediment or preventing the deposition of this matter which discourages the deposit feeders. Animals that are capable of switching their feeding behaviour, such as the amphipods, can therefore exist in environments of rapidly varying flow conditions as found in Kelsey Creek.

Some of the other University of Washington studies also examined benthic organisms in Kelsey and Bear Creeks during this project. Richey (pp.101, 102 and 181-182) found that even though the numbers of organisms were not significantly different between Kelsey and Bear Creeks, there was a greater weight of organisms per square meter in Kelsey Creek. The upstream stations in Kelsey Creek also supported a more diverse community of benthic macroinvertebrates than the downstream reaches.

The soluble lead levels in the interstitial water which are in most contact with the benthic organisms were low suggesting that metal toxicity is not a severe problem in Kelsey Creek. The metal toxicity, however, may have a low level potential problem in Kelsey Creek.

Richey (pp. 181 and 182) found frequent dense beds of large clams (Unionidae) in Bear Creek while they were not found in Kelsey Creek. The clams found in Bear Creek were large, indicating a stable and long population. These clams are very sensitive to heavy siltation and bed instability. They depend upon fine particulates carried in the water column for their diet. Therefore, it is not surprising that they were not found in Kelsey Creek. The high inorganic content in the suspended solids in Kelsey Creek and the unstable nature of the channel bed probably prevents their survival in Kelsey Creek. However, empty shells were found buried in the Kelsey Creek stream bed and no live organisms were observed. Therefore, they probably existed in Kelsey Creek in the past but they had been gradually excluded by a shifting habitat and a gradual decrease in the quality of the available food and problems associated with channel instability.

9. Fish

Scott, Steward, and Stober (pp. 39 and 53) reviewed two earlier studies that examined the fish populations in Bear and Kelsey Creeks. They stated that Kelsey Creek was a major producer of coho salmon and also supported significant numbers of cutthroat trout and kokanee salmon at one time. A 1956 survey, however, indicated that the Kelsey Creek salmon population was already in jeopardy due to increased urban development. Another study in 1972 found that the cutthroat were more abundant than the coho. Kokanee populations are noted to have recently declined throughout the Lake Washington drainage area because of the successful introduction of sockeye salmon in major tributaries. This 1972 study also observed occasional chinook salmon in Kelsey Creek. Food availability was determined not to be a limiting factor in the fish populations at that time. This earlier study did, however, find that a new culvert at the lower end of Kelsey Creek did block upstream fish passage under certain flow conditions. This problem was then corrected and the major factor impairing salmon reproduction in the urban streams was thought to be siltation resulting from construction activities.

The University of Washington fishery study in Bellevue (ref. 9) examined fish life in Kelsey and Bear Creeks for three years ending in 1981. Figure 5 summarizes the fish biomass observed at these two creeks by different species during an example month of August in 1981. Coho was found to comprise only a small fraction of the salmon found in Kelsey Creek but they frequently exceeded 50 percent of the total salmon population of Bear Creek. There was also a limited number of cutthroat trout older than age II inhabiting Kelsey Creek. Cutthroat of up to age III were found in Bear Creek, although limited in numbers. The Kelsey Creek salmon were reduced substantially in 1980 relative to both 1979 and 1981. The maximum salmon density in Kelsey Creek in 1981 was about one fish per three cubic meters which was less than 30 percent of what was observed in 1979 and 1981. The salmonid population of Bear Creek during this three-year period was also unstable as the density of salmon increased in each succeeding year.

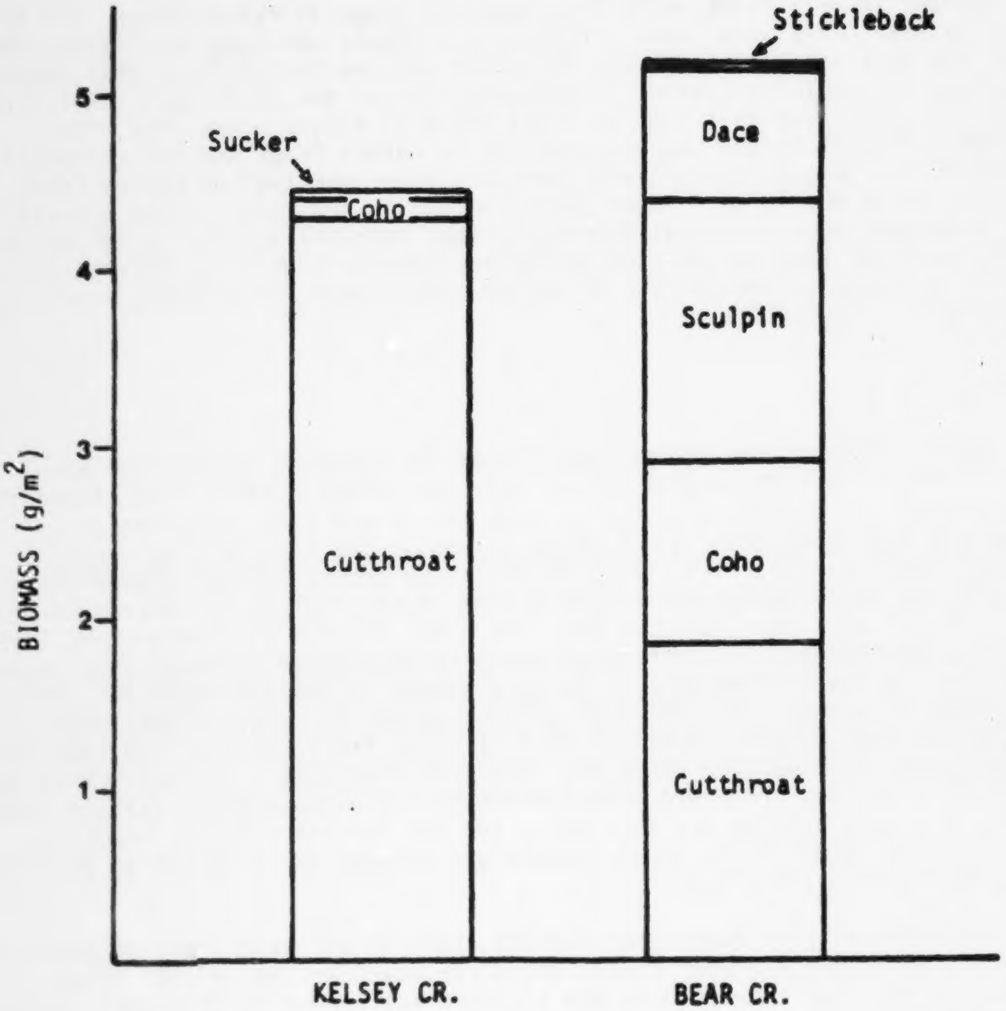


Figure 5. Average biomass of fish at sample sites in Bear and Kelsey Creeks, August 1981.

The dominant seasonal trends of fish biomass in Kelsey Creek showed a rapid buildup of biomass in the late winter and early spring followed by a sharp decline in early summer. The generally increasing trend of salmonid biomass in Bear Creek ended with a maximum of 3.7 grams/square meter in May of 1981. The maximum biomass in Kelsey Creek was about six and one-half grams/square meter in comparison. Non-salmon fish species were also quite abundant in Bear Creek, mostly made up of various species of sculpins and dace. Non-salmonids in Kelsey Creek were not very important with only a few large scale sucker found. Some dace stickleback and sculpin were also found in Kelsey Creek but in very small numbers.

When all fish species are considered, it is found that Bear Creek supports a greater quantity of total fish biomass (5.2 grams/square meter) versus 4.5 grams/square meter in Kelsey Creek. Also, no single grouping of fish accounted for more than about 35 percent of the total fish biomass in Bear Creek. The salmonid biomass in Kelsey Creek was greater than the salmonid biomass in Bear Creek. However, cutthroat trout comprised almost all of the salmon species found in Kelsey Creek while large populations of coho salmon were also found in Bear Creek along with the cutthroat trout. In comparison to some standards, the salmonid production in Bear Creek is low, the direct consequence of a depressed standing crop.

Scott, Steward, and Stober (pp.275-278) described the smolt production of the two studied creeks. They state that perhaps the best measure of the relative health of the stream in the Pacific Northwest is the number of smolts which it produces. The number of smolts in Kelsey Creek is approximately 40 percent less than that observed in other area creeks. The relative abundance of the cutthroat trout may explain the apparently poor salmonid smolt production of the Kelsey Creek watershed. Cutthroat trout require a larger territory than the typical coho smolt. Therefore, because of the large cutthroat population in Kelsey Creek, the smaller than normal smolt production may be expected. However, Valley and Richards Creeks, less impacted tributaries of Kelsey Creek, may tend to raise the average smolt production in the watershed.

The Kelsey Creek cutthroat appeared to grow considerably more rapidly than cutthroat observed previously in other streams. The average length of an age I cutthroat smolt in Kelsey Creek was close to the average length of an average age II cutthroat smolt in other streams. The Kelsey Creek age II smolts were typical of the lengths for other age III smolts. The average length of the coho in Kelsey Creek, however, was similar to the lengths produced in other streams in the Pacific Northwest. Also, most of the fish in Kelsey Creek outmigrated at age I with a considerable portion outmigrating at age II. Typically, cutthroat smolts from other streams generally outmigrate from ages II through IV. It is believed that the cutthroat migrating from Kelsey Creek spend an additional year in Lake Washington before entering Puget Sound.

Scott, Steward, and Stober (pp.10 and 11) summarize the potential effects of sedimentation on stream-living salmon. These include the clogging and abrasion of gills, abrasion or adherence of sediment to the egg chorion, increasing susceptibility to diseases, modification of behavior, blocking emergence of alevins, reducing spawning habitat, changing intragravel permeability with reduced dissolved oxygen concentrations, the introduction of potentially toxic materials associated with the suspended material, and altering the structure and productivity of the food resources available to the fish. They studied the incidence of damaged gills on the fish in Kelsey and

Bear Creeks (ref. 9, pp.253-257). They found that from 0 to 77 percent of the fish sampled in Kelsey Creek were afflicted with respiratory anomalies. The season and location along the channel length, as well as the age and species of the fish, affected these anomalies. Cutthroat, as an example, had afflictions that rapidly increased after mid-May. Older cutthroat also had less incidence of gill damage. Small coho salmon in Kelsey Creek had little gill damage. They also note that the incidence of damage to gills in the cutthroat trout in Kelsey Creek generally decreased in a downstream direction. No cutthroat trout and only two of the coho salmon sampled in Bear Creek had damaged gills.

Scott, Steward, and Stober also addressed water quality factors that may affect the salmon population (pp.271-281). The pH levels observed in Kelsey and Bear Creeks were well within the tolerances of all salmon life stages. They also found that the un-ionized form of ammonia (ammonium) also was about one-tenth the concentration that may present problems. However, the interstitial water concentrations of dissolved oxygen in Kelsey Creek were below values conducive to salmonid embryo survival.

Instream embryo bioassays indicated that coho embryo salmon survival was significantly greater in Bear Creek but that no difference was found when using rainbow trout embryos. Streamside bioassays, however, indicated that the surface waters of Kelsey Creek did not significantly reduce the survival of the salmon embryos. The survival of the embryos during the winter bioassays was significantly greater in Bear Creek than in Kelsey Creek but there was no difference in survival noted during the spring bioassay tests. While the laboratory and field bioassays tended to indicate minimal toxic influences, other field observations suggested a stronger possiblity of toxic problems. Coho salmon were absent in the more heavily developed areas and the incidence of cutthroat trout with gill damage increased in those areas. Higher levels of toxic pollutants, such as lead, were occurring with the increases of sediment transport in these more developed areas and may have contributed to the observed increase in gill damage.

Creek flows may also significantly affect the salmon fisheries. Scott, Steward, and Stober (pp.270 and 281) state that high creek flows may increase the sweeping of poor swimming fish from the creeks. The highest flows where migration of fish from the creek was monitored was a little over four cubic meters per second which was less than one-third of the peak flows recorded during the study period on Kelsey Creek. At these monitored flows, the species with relatively poor swimming abilities were swept from the system while the salmon were better able to withstand these increased flows. They estimated that a flood with a recurrence interval of about five years in Kelsey Creek having a peak instantaneous discharge of about 11 cubic meter/second may be expected to increase the coho embryo mortality by about 20 percent. This would increase the scour mortality during a five-year flood to ten percent or less. The lower summer flows during the summer may also limit the survival of some salmon populations (especially coho salmon) (ref. 8, p.56).

Richey (p. 216) states that the fish population in Kelsey Creek has adapted to the urban stream by shifting their species composition from coho salmon to cutthroat trout, and by making extensive use of less disturbed refuge areas. Most of these refuge areas are in the upper reaches of the stream and in its tributaries, and the existence of less disturbed midstream areas with deep pools and cover also provide protection. Some of the downstream areas that are prone to flooding and increased channel instability and sedimentation problems have presented problems for fish survival.

Pedersen (abstract) states that the salmon in Kelsey Creek seem to be adjusting their feeding to invertebrates that are present based upon fish stomach content analyses. Their growth did not appear to be limited by the type of diet available in Kelsey Creek. The salmon fishery in Kelsey Creek seems to be surviving; the City of Bellevue and the Municipality of Metropolitan Seattle have supported the installation and maintenance of streamside boxes for the incubation of sockeye salmon eggs. This program has provided a direct involvement with the local school children and, therefore, also serves the educational aspects of the beneficial uses for these urban streams.

10. Creek Sediment Quality

Several of the University of Washington projects and the Seattle METRO project investigated physical and chemical characteristics of the Kelsey and Bear Creeks sediments. Perkins (p. 7) stated that the size and composition of the sediments near the water interface tended to be more variable and of a larger median size in Kelsey Creek than in Bear Creek. These particle sizes varied in both streams on an annual cycle in response to runoff events. Larger particle sizes were more common during the winter months when the larger flows were probably more efficient in flushing through the finer materials. Pedersen (p.89) also states that Kelsey Creek demonstrated a much greater accumulation of sandy sediments in the early spring. This decreases the suitability of the stream substrates for benthic colonization. Scott, Steward, and Stober (pp.267 and 269) state that the level of fines in the sediment samples appears to be a more sensitive measure of substrate quality than the geometric mean of the particle size distribution. Fines were defined as all material less than about 840 microns in diameter. They also found that dissolved oxygen concentrations were better correlated with the percent fines than with the median particle size value.

Galvin and Moore analysed several Kelsey and Bear Creeks sediment samples for organic and metallic priority pollutants. Table 12 summarizes these observations for heavy metals in the sediments. These were whole sediment analyses which were not differentiated by particle size. Some of the sampling locations in Kelsey Creek were characterized by medium-coarse sediments while other sampling sites were characterized by finer sediment material. The Bear Creek samples were all in the medium-coarse sediment sizes. When the Kelsey and Bear Creek medium-coarse constituent concentrations were compared, it was seen that beryllium, cadmium, and chromium were all between two and three times greater in the Kelsey Creek material than in Bear Creek. However, the differences in quality between the fine sediments and the medium-coarse sediments in Kelsey Creek were typically greater than the quality differences between Bear and Kelsey Creek sediments of similar size. Specifically, the lead concentrations in finer materials were about 16 mg/kg while it was only three mg/kg in the medium-coarse material in Kelsey Creek. These sediment concentrations are all expressed as wet weight with the dry weight concentrations being approximately three times greater. They found that the Kelsey Creek sediments tended to have the highest metal concentrations and that arsenic, lead, cadmium, chromium, and zinc usually exceeded the natural background levels. The observed concentrations in Kelsey Creek were not as high as expected, possibly because

Table 12. Metallic Priority Pollutants found in Kelsey and Bear Creek Sediments (wet weight, mg/kg)

Mean Values ± approx. standard deviation

Constituent	Kelsey Creek Medium-Coarse (1)	Kelsey Creek Fine (2)	Bear Creek Medium-Coarse (3)	Ratio of Kelsey to Bear Medium-Coarse
Arsenic	11 ±6	14 ±2	8 ±3	1.4
Beryllium	0.12 ±0.01	0.18 (4)	0.05 ±0.02	2.4
Cadmium	0.09 ±0.03	0.26 (4)	0.04 ±0.01	2.3
Chromium	55 ±12	26 ±13	17 ±6	3.2
Copper	5 ±0.5	10 ±0.6	3 ±2	1.7
Lead	3 ±1	16 ±9	2 ±1	1.5
Nickel	10 ±2	15 ±2	6 ±3	1.7
Zinc	32 ±6	48 ±10	23 ±5	1.4

(1) 3 Samples
(2) 3 Samples
(3) 5 Samples
(4) 1 Sample

Source: Galvin and Moore (ref. 2, table 69)

of dilution of the more polluted particulates entering from the storm drainage system by less contaminated soils from stream bank erosion.

METRO (ref. 2, Table 70) also analysed organic priority pollutants in 17 creek sediments including several in Kelsey and Bear Creeks. Table 13 summarizes the observed organic concentrations found in these two study streams. Very few organic compounds were detected in either stream with the most notable trend being the much more common occurrence of various PAHs in Kelsey Creek while none were detected in Bear Creek. It is interesting that very little pentachlorophenol was found in the sediments, since it is one of the more common organic priority pollutants detected in urban runoff. METRO (ref. 2, p.5-3) summarizes the physical properties occurring in Kelsey Creek that control channel erosion. Scouring, and sediment transport were predominant and prevented the potential toxic buildup of these priority pollutants in the sediments.

Scott, Steward, and Stober (p.293) state that streambed substrate quality can be an important factor in the survival of salmonid embryos. Richey (pp.117-119) describes sediment bioassay tests which were performed using Kelsey and Bear Creeks sediments. She found that during the four-day bioassay experiment, no mortalities or loss of activities were observed in any of the tests. She concluded that the chemical constituents in the sediment were not acutely toxic to the test organism. However, the chronic and/or low level toxicities of these materials was not tested.

11. Lake Washington Sediment Quality

Seattle METRO (ref. 2, pp.3-116 to 3-120) analysed 12 Lake Washington samples for metallic and organic priority pollutant analyses. Nine of these samples were from embayments; five of which had direct urban stream inputs, one was below a storm drain outfall, and another was near shore away from any discharges. One of the samples was from the deep central part of the lake. Tables 14 and 15 summarize these observations. They only found small differences in trace metal concentrations between the various sites. The greatest variation was for chromium, lead, nickel, and silver which varied by approximately an order of magnitude between the minimum and the maximum values. However, no one site had high concentrations of most of the constituents. The arsenic, copper, lead, mercury, and zinc concentrations in the lake sediments appeared to be elevated above background levels. Very few organic priority pollutants were detected in the lake sediments during these analyses but previous work by METRO found a wide variety of organic pollutants. The lake sediment metal and PAH concentrations were similar to those detected in Kelsey Creek sediments.

12. Creek Bank and Streambed Erosion

Richey (pp.40, 44, and 56) made some observations about bank stabilities in Kelsey and Bear Creeks. She notes that the Kelsey Creek channel width has been constrained during urban development. Thirty-five percent of the Kelsey Creek channel mapped during these projects was modified by the addition of some type of stabilization structure. Only eight percent of Bear Creek's length was stabilized. Most of the stabilization structures in Bear Creek were low walls in disrepair while more than half of the structures observed

Table 13. Organic Priority Pollutant Observations in Kelsey and Bear Creek Sediments (mg/kg).

	#24-Kelsey Creek (1) 8/6/81	#54-Kelsey Creek (2) 3/2/82	#28-Bear Creek (1) 8/7/81	#69-Bear Creek (2) 5/20/82
PHENOLICS				
4-nitrophenol	ND	ND	ND	100
Pentachlorophenol	ND	ND	ND	60
2,4 dimethylphenol	ND	77	ND	ND
PHTHALATES				
Bis (2) ethylhexyl	39	ND	ND	ND
Butyl benzyl	320	ND	720	ND
PAHs				
Phenanthrene	26	50	ND	ND
Pyrene	28	83	ND	ND
Fluoranthene	30	72	ND	ND
Benzo(a)pyrene	ND	38	ND	ND
Benzo(k)fluoranthene	ND	79	ND	ND
Chrysene	ND	72	ND	ND

(1) Sampled using an aluminum scoop (surface material)

(2) Sampled using a freezing-core sampler (sediment profile)

Note: Other sediment samples were analyzed, but no organics were detected, except for Juanita and Thornton Creeks.

Source: Galvin and Moore (ref. 2, table 70).

Table 14. Metallic Priority Pollutants and Cyanides in Lake Washington Sediments (mg/kg, wet weight) (12 samples analyzed)

Constituent	Mean	Min.	Max.	Estimated Standard Deviation
Arsenic	7.3	3.6	11	2.3
Beryllium	0.03	< 0.06	0.08	0.01
Cadmium	0.09	< 0.4	0.24	0.03
Chromium	17.6	8.8	50	12.2
Copper	9.2	4.9	13	3.5
Lead	31.2	8.0	88	21.7
Mercury	0.05	0.03	0.08	0.01
Nickel	11.9	3.3	23	5.7
Silver	0.09	< 0.04	0.4	0.05
Zinc	31.1	18	47	9.5
Cyanides	all < 0.1	-	-	-

Source: Galvin and Moore (ref. 2, table 72)

Table 15 Organic Priority Pollutant Observations in Lake Washington Sediments (μg/kg). (12 samples analyzed).

PESTICIDES:	
Dieldrin	0.50
4,4-DDE	2.2, 2.6
4,4-DDD	4.6, 5
β-endosulfan	5
γ-BHC	0.42
HALOGENATED ALIPHATICS:	
1,1,-trichloroethane	71
Methylene chloride	550(a)
MONOCYCLIC AROMATICS:	
Toluene	300, 7
PHTHALATE ESTERS:	
Butylbenzyl phthalate	500(b), 160(b)
PAHs:	
Fluoranthene	72
Benzo(a)pyrene	61
3,4-benzofluoranthene	54
Benzo(k)fluoranthene	54
Pyrene	54, 83, 51

a) laboratory contamination likely
b) contamination possible

Source: Galvin and Moore (ref. 2, table 73).

along Kelsey Creek were large riprap or concrete retention walls. The necessity of the stabilization structures was evident from the extent and severity of erosion cuts and the number of deposition bars observed along the Kelsey Creek stream banks. Bridges and culverts were also frequently found along Kelsey Creek; these structures further act to constrict the channel. As discharges increase and the channel width is constrained, the velocity increases causing increases in erosion and sediment transport.

The use of heavy riprapping along the creek seems to worsen the flood problems. Storm flows are unable to spread out onto a flood plain and the increased velocities are evident downstream along with increased sediment loads. This rapidly moving water has enough energy to erode unprotected banks downstream of riprap. Many erosion cuts along Kelsey Creek downstream of these riprap structures were found. Similar erosion of the banks did not occur in Bear Creek. Much of the Bear Creek channel had a wide flood plain with many side sloughs and back eddies. High flows in Bear Creek could spread onto the flood plains and drop much of their sediment load as the water velocities decreased.

13. Creek Sedimentation and Sediment Transport

The University of Washington studies also examined sediment transport in Kelsey and Bear Creeks. Richey (p. 57) found that the relative lack of debris dams and off channel storage areas and sloughs in Kelsey Creek contributed to the rapid downstream transit of water and materials. The small size of the riparian vegetation and the increased stream power probably both contributed to the lack of debris in the channel. It is also possible that the channel debris may have been cleared from the stream to facilitate rapid drainage. The high flows from high velocities caused the sediments to be relatively coarse. The finer materials were more easily transported downstream. Larger boulders were also found in the sediment but were probably from failed riprap or gabion structures.

The effects of erosion and sediment deposition in Kelsey Creek were more severe than found in Bear Creek. Kelsey Creek's channel was scoured to deeper depth, there was much more channel instability in Kelsey Creek, and the numbers of erosion cuts and deposition bars were much more frequent in Kelsey Creek. Richey (pp.93-97) reported that the sediment transport in Bear Creek during December of 1979 was 27 kg/ha while 98 kg/ha left Kelsey Creek. The suspended solids transport was almost exponentially related to discharge. More than half of the daily transport of total suspended solids in Kelsey Creek occurred with flows that existed less than ten percent of the time. In Bear Creek, 50 percent of the annual solids was discharged with flows that occurred during about 20 percent of the time. These differences were probably the result of the increased stream power in Kelsey Creek. On an annual basis, Kelsey Creek discharged almost four times as much suspended solids as did Bear Creek, but most of this material passed through the stream in a few hours or days.

Richey (pp. 119-121) found that much of the solids transport in Kelsey Creek occurred during the rapid rise of the hydrograph when the energy to move sediment material was increasing. The silts and associated pollutants were rapidly transported through the system during these periods. The scouring of the channel appeared to remove temporarily stored silts and the associated pollutants. The higher levels of particulate transport in Kelsey Creek are probably because of increased stream power rather than because of increased sources of sediment material in the watershed. However, there were substantial amounts of instream sources of sediment material in Kelsey Creek to augment the runoff discharged sediment. Because of the lack of debris dams in the downstream sections of Kelsey Creek, the transported materials are carried significant distances before deposition. The high stream power available to transport the materials and the erodable nature of the stream banks in the watershed areas along with the lack of storage sites along the stream all contributed to high particulate yields from Kelsey Creek. Because much of the suspended particulate material in Kelsey Creek was from the relatively unpolluted bank materials, the sediments and suspended loads in Kelsey Creek had much lower concentrations of many of the typical urban pollutants compared to the urban runoff that was discharged to the creek.

The deposition of sediments in Kelsey and Bear Creeks were also studied by the University of Washington projects. Richey (pp.46-55) reported that sands and boulders were both found in Kelsey Creek while large boulders were almost nonexistent in Bear Creek. The Bear Creek sediments were more uniformly distributed than those found in Kelsey Creek. Major sediment deposition can occur in Kelsey Creek. During the late winter of 1980, sand bar depositions were so extreme in one area that the channel completely changed its course and cut a new channel through an adjacent area. Other changes in channel configuration due to the buildup of deposition bars were observed following some large storms in the 1980-81 winter. The Kelsey Creek channel appeared to be very dynamic and capable of frequent changes in flow and sedimentation. Such extremes in channel siltation and erosion were not observed in Bear Creek although some sand deposition bars did infrequently occur.

Much of the sediment deposition occurs during the falling limb of the hydrograph. The energy available to carry the suspended load decreases dramatically as the water velocity slows. Therefore, previously suspended solids can be deposited in the stream channel. As an example, during a single storm in 1980 the silt deposition in Kelsey Creek increased by about three times at one station. Much different deposition patterns were observed in Bear Creek. In Bear Creek the lower solids concentrations and a more gradual decrease in creek water velocity resulted in much less sediment deposition following storm events.

On an annual basis, the accumulation of fine silts in the sediments was greater in Kelsey Creek than in Bear Creek, but these depositions were very temporary in nature. The silts were moved rapidly downstream and were replaced by new deposits from upstream. Therefore, there was essentially no accumulation of the fine silts in the interstices of the larger material of the Kelsey Creek sediments. The tight packing of the surface gravels possibly prevented the penetration of these rapidly moving fines further down in the sediment layers. The surface of the Kelsey Creek sediments had large amounts of fine material for short periods of time, but the finer material was lacking at deeper depths in the sediment. Pedersen (p.89) stated that little filling of the interstitial voids between the larger sediment substrates was very important in maintaining a productive stream. These open cobble areas permit maximum habitation of benthic organisms around the cobbles. Fine sediments would clog these areas restricting access except to specialized burrowing organisms. The surface layer of fine sediments in Kelsey Creek, however, could restrict the penetration of certain organisms to these more open, deeper voids.

B. SOURCES OF URBAN RUNOFF POLLUTANTS

1. Atmospheric Particulate and Rainfall Deposition of Pollutants

The USGS (refs. 1 and 6) studied dustfall quantity and quality along with rain quality at each of three locations in the test watersheds. Table 16 (ref. 1, Table 31) summarizes the major cation and anion concentrations in Bellevue rainwater. These were all from a few samples collected between September and the end of November, 1981. The observed concentrations of these major ions were all very low, but sodium, sulfate, and chlorides were important constituents.

Table 17 (ref. 6, Table 1) summarizes the observed concentrations in the rain and also the dry atmospheric deposition quality. There are many more samples represented on Table 17 covering the complete study period. Both Tables 16 and 17 combine the data for all three study locations. Few differences were found between the constituent concentrations in rain for the different sampling sites (ref. 6, p. 18). However, the dry atmospheric deposition concentrations had significant differences between concentrations at the different sampling sites for many constituents. These differences in dry dustfall quality, however, are expected to be more a cause of inadequacies in the sampling methods and locations of collectors in the catchment rather than to differences in the concentration of the actual material sampled. The data were uniformly consistent in that all dry deposition constituent concentrations were higher at Lake Hills than at Surrey Downs or at 148th Avenue S.E. These differences may have been caused by sampling deficiencies, including probable removal of material from the collectors by rain, and the possibility that the collectors were not placed in representative locations.

Seattle METRO also examined the quality of atmospheric particulates. Tables 18 and 19 summarize the results of metallic and organic priority pollutant analyses conducted on two sets of high volume suspended particle filters. The first set of filters, comprising 40 different sampling periods, was collected between January and October of 1976 while the second set of filters was from ten sampling periods collected in December of 1981 (ref. 2, Tables 47 and 50). The analyses of these two sets of high volume air filters resulted in two different data sets. The same 11 metals and cyanides of the 14 total were detected in both filter groups, but the last filter group had concentrations about one order of magnitude less than the first group. Zinc, lead, copper, arsenic, nickel, and chromium were the most important inorganic priority pollutants detected on these filters during both sampling periods. Galvin, however, notes that the atmospheric dustfall material could be different from the material included on the suspended solid high volume filters (ref. 2, p.3-75).

The organic priority pollutant analyses from METRO are shown on Table 19. These are the same two sets of high volume filters that were analysed for the inorganic priority pollutants and shown previously. In this case, contamination of phthalates was possible during the first sampling period due to high blank concentrations found. None of the insecticides or phenols detected in the second set of samples were detected in the first set. Most of

Table 16 Major Cation and Anion Concentrations in Bellevue Rain

Constituent	Max.	Min.	Median	# of Samples
hardness, mg/l as $CaCo_3$	1	0	1	7
acidity, mg/l as H	-	-	0.2	1
Calcium, mg/l as Ca	0.4	0.1	0.1	9
Magnesium, mg/l as Mg	0.1	<0.1	<0.1	8
Sodium, mg/l as Na	0.6	<0.2	0.2	9
Potassium, mg/l as K	0.1	0.1	0.1	8
Alkalinity, mg/l as $CaCo_3$	-	-	1.0	1
Sulfate, mg/l as SO_4	5.0	0.3	1.0	9
Chloride, mg/l as Cl	1.0	<0.1	0.5	9
Fluoride, mg/l as F	0.09	0.03	0.06	9
Bromide, mg/l as Br	<0.05	<0.05	<0.05	7
Silica, mg/l as SiO_2	<0.1	<0.1	<0.1	9

Samples collected at Surrey Downs, Lake Hills, and 148th Avenue S.E. between 9/22 and 11/30/81.

Source: Ebbert, Poole, and Payne (ref. 1, from Table 31).

Table 17 Atmospheric Deposition Chemical Composition

Wet Atmospheric Deposition Composition (mg/l, except as noted)				
Constituent	Max.	Min.	Approx. Median	# of Samples
Specific conductance (µmhos/cm)	76	6	18	116
ph (ph units)	5.4	2.8	4.4	116
Dissolved solids	44	<1	3	46
Suspended solids	21	<1	3	78
Dissolved organic carbon	12.3	<0.1	1.7	105
Suspended organic carbon	1.6	<0.1	0.2	100
Chemical oxygen demand	113	1	11	103
Nitrate plus nitrite, as N (dissolved)	3.6	<0.01	0.13	111
Ammonia, as N (dissolved)	0.31	<0.001	0.090	110
Dissolved Kjeldahl nitrogen as N	1.2	0.02	0.33	98
Total Kjeldehl nitrogen as N	1.8	0.12	0.45	116
Phosphorus, dissolved as P	0.13	<0.001	0.008	116
Total phosphorus, as P	0.16	<0.001	0.008	116
Dissolved lead	0.011	<0.001	0.003	19
Total lead	2.3	<0.001	0.011	115

Dry Atmospheric Deposition Composition (grams/kg total solids)				
	Max.	Min.	Approx. Median	# of Samples
Total solids (kg/ha/yr)(1)	620	28	83	70
Total organic carbon	680	22	17	55
Chemical oxygen demand, as O_2	3,500(?)	50	790	65
Nitrate plus nitrite, as N	83	0.01	7	56
Ammonia, as N	36	<0.01	6	54
Total Kjeldahl nitrogen, as N	66	1.9	27	65
Total phosphorus, as P	27	0.16	1.1	62
Total lead	17	0.10	1.6	70

(1) lbs/acre x 1.13 = kg/ha, typical sampling period was one month.

Source: Prych and Ebbert (ref. 6 from Table 1).

Data from Surrey Downs, Lake Hills, and 148th Avenue S.E. combined.

Table 18 Metal Concentrations of Atmospheric Suspended Solids from the Duwamish Valley, Seattle

Constituent	Composite High-Volume Suspended Particle Filters (mg/kg suspended solids)	
	January to October, 1976(1)	December, 1981(2)
Antimony	56	1.9
Arsenic	360	51
Beryllium	ND	ND
Cadmium	23	2.5
Chromium	180	15
Copper	950	60
Lead	1,700	390
Mercury	6	0.39
Nickel	200	21
Selenium	45	1.4
Silver	4.2	0.69
Thallium	ND	ND
Zinc	3,100	140
Cyanides	ND	ND

(1) Composite of 40 filters
(2) Composite of 10 filters

Source: Galvin and Moore (ref. 2, Table 47).

Table 19 Priority Pollutant Organic Compounds Detected on Atmospheric Suspended Solids from the Duwamish Valley, Seattle

Constituent	Composite High-Volume Suspended Particle Filters (mg/kg suspended solids)	
	January to October, 1976 (1)	December, 1981(2)
4,4'-DDE	ND	4.6
Endosulfan Sulfate	ND	25.0
Endrin	ND	12.0
Pentachlorophenol	ND	1,700
4-nitrophenol	ND	2,300
Bis(2-ethylhexyl) phthalate	(3)	4,900
Butylbenzyl phthalate	(3)	ND
Di-n-butyl phthalate	(3)	1,200
Di-n-octyl phthalate	3,000	ND
Diethyl phthalate	22,000	ND
Phenanthrene	2,000	ND
Fluoranthene	ND	720
Pyrene	4,000	1,400
Benzo(a)anthracene	7,000	1,900
Chrysene	9,000	1,400
Benzo(k)fluoranthene	12,000	4,200
Benzo(a)pyrene	3,000	1,700
Indeno (1, 2, 3-cd)pyrene	17,000	720
Benzo(ghi)perylene	ND	3,700

(1) composite of 40 filters
(2) composite of 10 filters
(3) very high blank sample concentrations, possible contamination

Source: Galvin and Moore (ref. 2, table 50).

the organics found on these filters were the polycyclic aromatic hydrocarbons (PAHs). The ranking of the PAHs for these suspended particulates was quite different than that found for the street dirt. The higher molecular weight (four to six ring) PAHs are dominant by weight in the suspended solids samples while the lower molecular weight (two to four ring PAHs) were dominant in the street dirt samples. This suggests that the airborne PAHs are combustion products while the street dirt PAHs are from petroleum product spills. Two phenols were also noted in high concentration in the later set of suspended solids filters that are also dominant in the street dirt samples.

The concentrations of these different constituents, both in rain and as dry atmospheric dustfall samples, were used in conjunction with the total rainfall and dustfall quantities measured to determine the annual atmospheric deposition rates. Table 20 summarizes these values with information from Surrey Downs, Lake Hills, and 148th Avenue S.E. combined. The USGS (ref. 6, pp.38-45 and 123) points out that the dry atmospheric deposition collectors may not have been efficient in retaining materials that were deposited into them; they feel that the actual deposition amounts were probably greater than those that were observed. The differences in the amounts of material collected at the different sampling locations therefore are probably not indicative of differences in the actual sites. The chemical concentration information presented earlier should be good indicators of the quality of this material. The amount of material obtained in the dry deposition collectors did not correlate very well with the exposure time. They (ref. 1, p.13) also note that the dry deposition sampler in Lake Hills was periodically contaminated with bird droppings. This problem was corrected part way through the sampling period and all the samples that were known to be contaminated by the bird droppings were discarded.

The average deposition values shown in Table 20 are annual estimates. The actual monthly variations of the depositions could vary substantially. Many of the constituents had much greater deposition rates both in the wet and the dry samples during the wet months of the year. However, there was substantial variation in the depositions for each month for the different study years. In August of 1980, ash from an eruption of Mt. St. Helens fell in the study area which substantially increased the dustfall measurements. These increased dustfall values were typically two to four times the average monthly dustfall values. In most months, and at all of the three stations, dry atmospheric dustfall was much greater than the total solids associated with the rainwater. A few very wet months, however, had more solids associated with the rainwater than with the interevent atmospheric dry deposition.

2. Runoff Water Sources

Before runoff sources can be evaluated, the rainfall characteristics must be examined. The City of Bellevue study (ref. 5, Section 4) examined the precipitation characteristics of about 400 rains that occurred at the two main study locations (Surrey Downs and Lake Hills) during the two years of the project. Some of the Bellevue rain characteristics significantly affected the expected runoff and receiving water conditions. Bellevue receives about one meter of rain each year, making it much wetter than most U.S. locations. However, some of the summer months in Bellevue are drier than the other months. The dry periods between the rain events are quite small even in the

Table 20 Annual Atmospheric Deposition(1)

Constituent	Wet Deposition		Dry Deposition		Total
	kg/ha/yr	% of total	kg/ha/yr	% of total	kg/ha/yr
Total solids	32	27%	88	73%	120
COD	210(2)	73	76	27	286(2)
Nitrate plus nitrite	2.2	76	0.66	24	2.9
Ammonia	0.83	64	0.46	36	1.3
Total Kjeldahl nitrogen	4.1	67	2.0	33	6.1
Phosphorus	0.10	36	0.18	64	0.28
Recoverable lead	0.18	55	0.15	45	0.33
Total organic carbon	19	66	10	34	29

(1) Surrey Downs, Lake Hills and 148th Avenue data combined.

(2) It is not known how the COD depositions can be greater than the total solids deposition.

Source: from Ebbert, Poole and Payne (ref. 1, Table 12).

dry season; dry periods of more than a week are quite rare but they may occur. Rains come on an average about once every two or three days throughout the year as shown on Table 21. Slightly more than 100 rains may occur each year, but the rain associated with each is quite small. Most of the rains are less than six mm in volume. The largest rains monitored during this project were about 100 mm.

The two-year period of study had fairly typical rains for Bellevue. Normal rain conditions are very important during an urban runoff study as abnormal rains can create large abnormalities in the runoff quantities. Similarly, the rainfall conditions at two test locations, especially if one is a test area and the other is a control area, must also be similar during the period of study. If the rainfall conditions vary between the test and control sites then the observed runoff yields might not be indicative of the control measure's effectiveness, but more an indication of the differences of the rains.

Rainfall monitoring began at the Lake Hills station in the middle of February, 1980, and about two weeks later at the Surrey Downs location. Rainfall monitoring was completed at the end of January, 1982, in both basins. Table 21 summarizes the rainfall conditions averaged for the different months of the year and for the Lake Hills and Surrey Downs sites combined. It was found that each storm during the wet season had about twice as much rain as the storms during the dry season. The wet season rains also lasted about one and one-half to two times as long as the dry season rains, and the maximum preceding interevent dry periods during the dry season were substantially greater than during the wet season.

The differences in Surrey Downs and Lake Hills rain conditions were studied based upon 165 rains that were completely monitored in each area during the two-year study period. The Lake Hills rains totaled about 12 percent more than the comparable Surrey Downs rains. The average duration of the Lake Hills rains was about ten percent longer than the Surrey Downs rains. The Lake Hills rains also started about one-half hour before the rains in Surrey Downs began. The ranges of the values for individual storm events, however, varied greatly. The total rain and duration ratios ranged from less than one-tenth to more than three times, while the time differences noted were as great as 16 hours.

Most of the rain events had less than six mm of rain and less than ten percent of the rain events had volumes greater than 25 mm. Most of the rainfall quantities were associated with rain events greater than about 15 mm. The much more common small rains did not add up to much volume. The rains that were smaller than six mm accounted for less than 25 percent of the total rainfall volume, while about 30 percent of the total rainfall volume was associated with rains greater than 25 mm.

As noted previously, much effort was made in analysing the differences in rain characteristics at the two test and control sites. About half of the rains that were observed simultaneously at both basins had a difference of rain quantity greater than plus or minus 20 percent. This difference was much greater for the small rains than for the large rains. As an example, several rain events measured about eight mm in one basin, while only measuring about 2.5 mm in the other basin. This can result in much more than a three to one difference in the observed runoff yields because of differences in runoff

Table 21 Bellevue Rain Conditions During Project Period
(February 1980 through January 1982)

Month	Rain per Month (mm)	Number of Rains per Month	Average Rain per Storm (mm)	Average Storm Duration (hrs)	Average Preceeding Dry Period (hrs)	Average Rain Intensity (mm/hr)	Peak 30 Min. Rain Intensity (mm/hr)
January(1)	91	11	8	12	53	0.8	2.3
February	84	6	14	22	70	0.5	3.6
March(2)	66	9	8	14	68	0.5	2.8
April	71	11	7	10	59	1.0	3.3
May	41	9	5	8	72	0.8	2.5
June	61	10	7	8	79	1.3	3.3
July	30	3	10	8	115	1.3	3.6
August	20	4	5	9	650	1.0	3.0
September	76	8	10	11	81	1.3	4.8
October(1)	94	7	12	11	110	0.8	3.6
November	142	14	10	12	37	1.0	3.8
December	163	16	10	12	34	0.8	3.6
Annual	940 total	108 total	9 average	11 average	120 average	1.0 average	3.3 average

(1) The wet season includes January, February, October through December.

(2) The dry season includes March through September.

Source: Pitt (ref. 5, from Table 4.1).

losses for different rain volumes. Differences for small rains are even more important because of the greater percentage losses that can occur because of infiltration and surface detention/storage. The percentage differences for the larger rains was less. A rain of about 27 mm in one basin could have corresponding rains of between 15 and 30 mm in the other basin.

Almost 400 runoff events were also monitored at the Surrey Downs and Lake hills stations during the two-year study period. Table 22 is a summary of these runoff characteristics summarized by month and averaged for the two basins combined. One of the interesting aspects of these Bellevue locations was the large quantity of base flow that contributed to the total annual urban flows. The base flow in the Surrey Downs basin accounted for about 23 percent of the total annual flow, while the base flow was only about 13 percent of the total annual flow in Lake Hills. There are also important differences in the runoff yields in the Lake Hills and Surrey Downs sites. The base flow in Lake Hills was only about 65 percent of the annual base flow in Surrey Downs, while the stormwater flows in Lake Hills were about 35 percent greater than in Surrey Downs. Overall, the base plus stormwater urban flows from Lake Hills were about 18 percent greater than Surrey Downs on an equal area basis. Most of the storm characteristics shown on Table 22 have quite different values for the dry period from March to September when compared to the wet period of October through February. Peak runoff flows were generated during September.

The amount of rain that drains off an urban area as urban runoff is dependent on many factors. These include such factors as soil moisture, soil infiltration capacity, rain intensity, and rain duration. The moist soil conditions in Bellevue (due to the rain frequency) tend to increase the fraction of rain that occurs as runoff (Rv), while the small volumes and small intensities of each individual rain allows much of the water to infiltrate into the soil or evaporate. For both study years and test basins, only about 25 percent of the rain that fell in the test basins left the areas as runoff. There was substantial scatter in this value, but the small rains typically had the smallest runoff factors while the large rains had the largest factors. Figure 6 is a plot of these Rv values (the ratio of unit area runoff divided by unit area rain). Small rains of about 2.5 mm have Rv values of about 0.1 for the dry season and about 0.2 for the wet season while rains of about 65 mm had Rv values of about 0.2 to 0.3 during the dry season and about 0.3 to 0.4 during the wet season. The runoff coefficient (Rv) value used in this report considers evaporation, detention storage, and soil infiltration. If the ground is wet at the beginning of the rain, or the total rainfall volume is large, then the Rv value is large. The soil can accept rain that is falling directly on it at a rate equal to its infiltration capacity. If this infiltration capacity is exceeded, then excess runoff will run off the soil. When rain falls on an impervious surface such as pavement or rooftops much of the rain will flow off the surface. The heat of the surface will cause some evaporation of the water upon contact (flash evaporation) and some of the rain will infiltrate through cracks or holes in the otherwise impervious surface. Water may also pond on the surface of an impervious surface for future evaporation and leakage. If the rain was very small most of the sheet flow would be gone before it has a chance to leave the impervious areas.

A simple model was developed based on these Bellevue rain observations. Almost 99 percent of the rains that occurred in Surrey Downs and 91 percent

Table 22 Urban Runoff and Base Flow Characteristics(1)

Month	Average Storm Discharge (mm)	Average Peak Discharge (1/sec/ha)	Average Storm Duration (hrs)	Average Runoff Coefficient (Rv)	Total Monthly Baseflow (m^3/ha)	Total Monthly Storm flow (m^3/ha)	Average Number of Storms per month
January	2.3	1.5	14	0.26	59	168	10
February	4.3	2.7	26	0.28	45	234	5
March	1.8	1.4	12	0.19	63	148	7
April	1.5	1.7	10	0.15	30	129	5
May	0.8	1.4	7	0.14	26	66	8
June	1.3	1.9	7	0.14	24	105	10
July	2.0	1.8	7	0.13	24	56	3
August	0.8	2.8	8	0.11	25	31	4
September	2.0	3.2	11	0.17	24	152	8
October	3.8	2.5	14	0.20	26	239	6
November	2.8	2.8	13	0.25	45	398	14
December	3.6	2.5	15	0.28	74	509	16
Annual							
average	2.3	2.2	12	0.21	39	186	8
total	27.0	--	--	--	465	2,235	96
Max. observed(2)	7.1	6.0	33	0.33	95	611	18

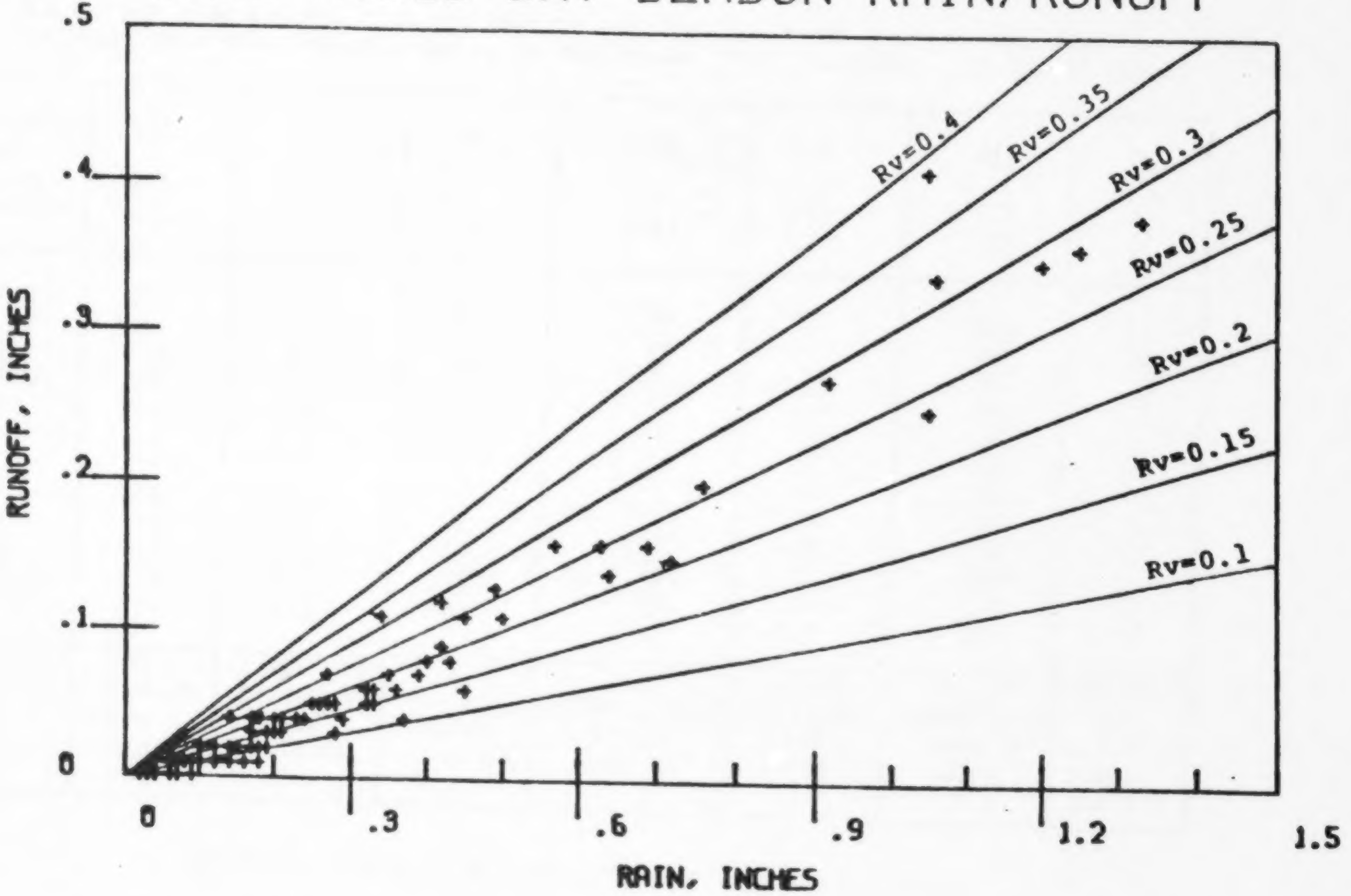
(1) Includes data averaged for Lake Hills and Surrey Downs combined. The Surrey Downs period was 3/80 through 1/82 (23 months) and Lake Hills was 2/80 through 1/82 (24 months).

(2) Maximum monthly average value, max. per storm values were much larger.

Source: Pitt (ref. 5, from Tables 5-4, A-6, and A-7).

FIGURE 6

LAKE HILLS DRY SEASON RAIN/RUNOFF



Source: Pitt (ref. 5, figure 5-1).

of the Lake Hills rains were monitored. These rain observations were divided by study period (wet and dry season) to account for varying antecedent soil conditions. Table 23 summarizes some of the results of these models for both Lake Hills and Surrey Downs for different seasons of the year and for different rain totals. Multiple regression analyses relating the Rv value to total rain, average rain intensity, peak rain intensity, and days since last rain were calculated for the different rain events. These analyses showed that the rainfall volume alone accounted for about 95 percent of the calculated Rv value. Peak rain intensity values accounted for between five and ten percent of the total Rv value. Increases in the peak intensities caused increases in the Rv value. As the number of rains since the last day increased the Rv value decreased. This antecedent factor reduced the Rv value by about five percent. These decreases in Rv with increases in antecedent dry conditions were probably due to drying soils. It was found that average rain intensities affected the Rv values by less than five percent. However, the season of the year was extremely important in determining the actual runoff and rainfall relationships. The Rv values for the winter wet months of November through February were about 35 percent larger than the Rv values for the drier summer months of March through October for the same rain characteristics. It was concluded that there is no real need to adjust the calculated Rv values based on rain intensity or preceding length of dry period. It was only necessary to consider total rainfall and season as shown in Table 23.

The USGS (ref. 6, pp.55-68) also analysed the runoff characteristics as a function of different rain characteristics. They found very high relationships for total runoff based only on the total rainfall. Maximum rain intensity and the rainfall duration also affected the runoff volume but to a lesser extent. Relationships between the peak discharge rate and the maximum rainfall intensity were also reasonably good. They also found that the total rain quantity accounted for more than 90 percent of the correlation between rain and total runoff.

These analyses showed that runoff characteristics can be reasonably predicted based on a few of the measured rain characteristics. It is much more difficult, however, to determine where in the watershed the runoff flows are originating. Source contributions were an important aspect of the City of Bellevue's project (ref. 5, pp.5-5 through 5-14). A model was developed based on the variations of the Rv value for different rain totals as described previously. The contributions from the specific land covers in each of the two basins and the distribution of the observed rains during the two-year study period were used in the development of this model. The land covers considered include vacant land, parks, back yards, front yards, roof tops, driveways, parking lots, and streets. These classifications of the impervious and pervious areas were mostly based upon their distance from the drainage system, their size, and the amount of surface disruption. For those areas that were far from the drainage system, much of the rainfall would likely infiltrate into the soil before reaching the drainage system. Large pervious areas such as vacant lots and parks may also have greater infiltration than front yards that are located adjacent to the drainage system. Roof tops, even though usually considered impervious, have most of their downspouts directed towards the surrounding back or front yards for infiltration. A portion of the driveways and parking lots were also directed toward surrounding pervious areas. All of the street surfaces, however, are directly connected to the

Table 23 Variation of Runoff Coefficient (Rv) by Study Area, Season, and Rain Total

Total Rain (mm)	Lake Hills		Surrey Downs	
	Wet Season	Dry Season	Wet Season	Dry Season
0.25	0	0	0	0
2.5	0.19	0.07	0.20	0.11
5	0.29	0.19	0.24	0.16
10	0.34	0.24	0.26	0.19
20	0.37	0.27	0.27	0.20
40	0.38	0.29	0.28	0.20
65	0.38	0.29	0.28	0.21

Source: Pitt (ref. 5, table 5.2).

drainage systems.

As previously described, the overall Rv values for the drainage basins were very small for small rains but increased rapidly to a fairly constant value. Figure 7 (ref. 5, Figure 5-5) shows the results of this modeling effort and the contributions of runoff flows from these different surface areas. For very small rains, no runoff is expected to occur from the pervious areas nor from the impervious areas that drain to these pervious areas. Starting at about 2.5 mm of rain, however, the runoff coefficients are about 0.3 to 0.5 times the maximum values that they are likely to obtain. The dry season runoff coefficients are less than the wet season values due to different soil moisture conditions. Therefore, slightly different contributions are associated with the two different areas for the two different seasons. This figure shows that for all rains greater than about 2.5 mm, impervious surfaces contribute more than 60 percent of the total urban runoff flows. The remainder of the flows are approximately evenly divided between front and back yards while vacant lots and parks contribute very little flow due to their limited presence in the area. Street surfaces contribute about 25 percent of the total urban flows for most rains causing runoff.

The USGS (ref. 6, pp.76-81) also evaluated the contribution of runoff flows from different source areas in the basins. They found through, a modeling effort, that most of the total runoff came from effective impervious areas. Effective impervious areas are those that drain directly to the drainage system and are not allowed to drain to pervious areas. These effective impervious areas contributed more than 90 percent of the flows in the basin studied. They conclude that the computed runoff volumes are a function mostly of the effective impervious areas and are not strongly dependent on soil moisture or infiltration factors. However, it was previously noted that there were significant differences in the Rv values for wet versus dry seasons that are most likely caused by the different soil moisture conditions, as these comparisons were made for rains having similar total quantities and intensity characteristics.

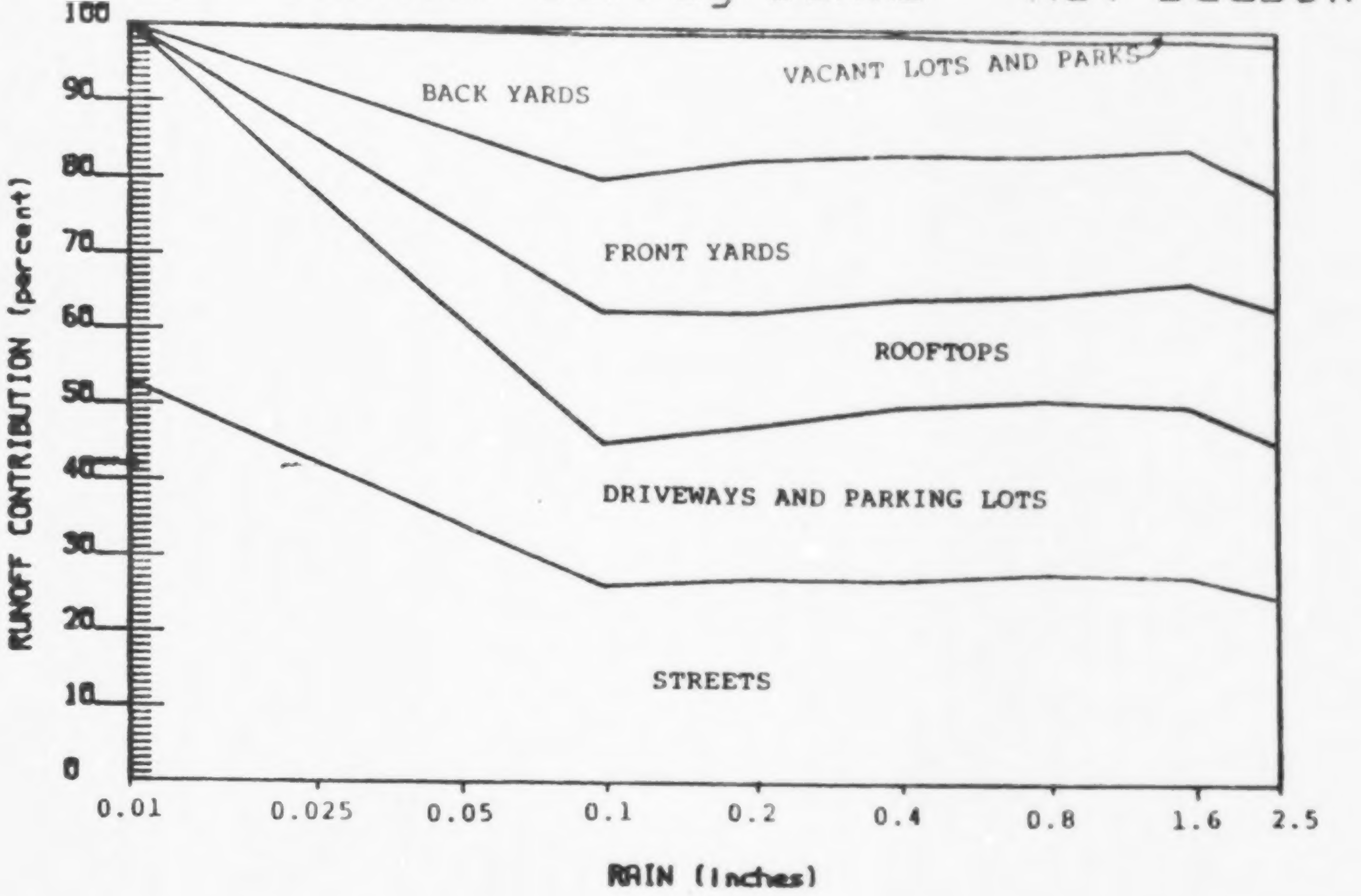
3. Stormwater and Baseflow Urban Runoff Quality and Pollutant Source Areas

Collecting stormwater runoff quality data was a major aspect of the City of Bellevue's and the USGS' projects. In addition, Seattle METRO analysed some of the samples collected by the City of Bellevue for metallic and organic priority pollutants. This subsection summarizes all of this available stormwater quality information.

The USGS (ref. 1, Table 20) analysed about 25 discreet stormwater samples for major anions and cations. These data are summarized on Table 24. There was a tremendous variation in major ion concentrations of the Bellevue stormwater. These variations are most likely caused by the large variations in storm flows represented in these samples. The USGS (ref. 6, p.19 and 116) found that when the stormwater runoff discharge was high, the concentrations of the constituents in suspended forms tended to be high and the concentrations of the constituents in dissolved forms tended to be low. During periods of low discharge, suspended concentrations were low and the dissolved concentrations were high. This is a relationship found in other

FIGURE 7

RUNOFF SOURCES Surrey Downs - Wet Season



Source: Pitt (ref. 5, figure 5-5).

Table 24 Stormwater Major Anion and Cation Concentrations

Constituent, mg/l	Max.	Min.	Median	# of samples
Hardness, as $CaCO_3$	170	7	24	25
Non-carbonate hardness, as $CaCO_3$	150	0	9	24
Alkalinity, as $CaCO_3$	25	0	12	23
Silica, as SiO_2	15	0.1	3	26
Calcium	34	2.3	7.9	25
Magnesium	20	0.3	1.1	25
Sodium	210	0.9	2.3	25
Potassium	11	0.6	1.0	25
Sulfate	61	2.6	9.4	25
Chloride	380	0.8	4.5	43
Fluoride	0.4	0.1	0.1	25

Data for Surrey Downs, Lake Hills and 148th Avenue S.E. combined

Source: Ebbert, Poole, and Payne (ref. 1, table 20).

urban runoff studies and indicates that much of the constituents in urban runoff is in suspended forms, while most of the base flow constituents are dissolved. As more and more runoff is added to the base flows, the suspended concentrations of the constituents increase. The USGS found, however, that the regression analyses of flows versus concentrations were not adequate for estimating the concentrations from the discharge data. Table 24 also shows that the hardness of the stormwater is generally very low.

Most of the analytical effort was associated with a core list of important constituents. Tables 25 and 26 summarize the USGS' and the City of Bellevue's stormwater quality data for these core constituents. The USGS, as noted in the methodology section, obtained many discreet samples throughout individual storms but only analysed data from a small percentage of the total storms that occurred during the study period. The City of Bellevue's sampling procedures involved collecting total storm flow-weighted composite samples throughout most of the events that occurred during the sampling period at the Surrey Downs and Lake Hills sites. The Table 25 USGS values combine the Surrey Downs and Lake Hills data along with 148th Avenue data. The City of Bellevue (ref. 5, p.6-23) also analysed the variations of stormwater quality with total storm flows. Log-transformed values of flow were compared with log-transformed values of storm yields for various pollutants. Very little and statistically insignificant variation in total solids concentrations were observed. As an example, the total solids concentrations associated with small runoff events (of about 30 to 300 cubic meters of total flow had concentrations of about 100 mg/L of total solids. When the runoff volumes increased substantially to about 3000 cubic meters for a single storm event, the total solids concentrations decreased to about 75 mg/L.

The USGS (ref. 6, p.91) found that about two-thirds of the total solids and phosphorus loads, and one-third of the ammonia plus organic nitrogen (total Kjeldahl nitrogen), total nitrogen, and organic carbon loads were in suspended forms instead of dissolved forms. There was very little variation in most of the constituent concentrations for each of the three sites for most rains. They also found that about 15 percent of the total nitrogen load is in the form of dissolved nitrate plus nitrite nitrogen, about ten percent is as dissolved ammonia, 40 percent is as dissolved organic nitrogen, and 35 percent was as suspended ammonia plus organic nitrogen (suspended Kjeldahl nitrogen). About 74 analyses were conducted to determine these nitrogen specie breakdowns.

Seattle METRO (ref.2, p.3-3) analysed about 21 of the total storm flow-weighted composite samples from Bellevue for the 14 metallic priority pollutants including cyanide. Table 27 summarizes these results. Arsenic, cadmium, chromium, copper, lead, and zinc were found in all of the samples analysed by METRO; nickel was found in more than half of the samples; while the other metals were all detected in well below half of all of the samples. These stormwater metal concentrations were very low when compared to other metal urban runoff data for other locations (except for arsenic). They also found that the stormwater metal concentrations did not vary significantly between the study areas. METRO also analysed many of the samples for dissolved concentrations of the different metals in addition to the total concentrations shown on Table 27. Only copper and zinc showed significant dissolved concentrations while the other metals were almost completely associated with the suspended particulates in the stormwater.

Table 25 Urban Runoff Quality Reported by the USGS
(Many Discrete Samples for a Limited Number of Storms)

Constituent, mg/l unless noted otherwise	Max.	Min.	Approx. Median	# of discrete samples
Temperature, ^{o}C	14.8	2.6	8.0	49
Specific conductance, µmhos/cm	1480	12	41	1299
pH (pH units)	7.9	3.4	6.7	1093
COD	780	8	60	681
BOD_5	40	<0.1	6.6	321
BOD ultimate	115	3.5	20	138
Suspended organic carbon	40	<0.1	2.1	638
Dissolved organic carbon	120	0.2	7.5	681
Fecal coliforms, #/100 ml	66,000	1	980	326
Suspended solids	2740	1	50	1180
Dissolved solids(1)	788	8	35	241
Nitrate plus nitrite, as N	4.5	<0.01	0.21	691
Ammonia, as N	7.2	<0.01	0.14	689
Total Kjeldahl nitrogen	45	0.21	1.1	687
Dissolved Kjeldahl nitrogen	33	<0.01	0.63	686
Total phosphorus	9.2	0.01	0.15	686
Dissolved phosphorus	7.2	<0.01	0.06	685
Lead	1.8	0.004	0.14	693
Oil and grease	10	<1	2.5	16

(1) estimated from specific conductance values.

Note: data for all Bellevue sites combined (most of the median values are averages of the three site medians): Lake Hills, Surrey Downs and 148th Avenue S.E.

Source: Ebbert, Poole, and Payne (ref. 1, from tables 11, 22 and 29).

TABLE 26 Urban Runoff Quality Reported by the City of Bellevue (total storm, flow-weighted composite samples for most events).

Constituent	Max.	Min.	Average	# of Total Storm Samples
Specific conductance, μmhos/cm	300	16	41	204
pH (pH units)	7.4	5.2	6.3	204
Turbidity (NTU)	150	4	19	204
Total solids (mg/l)	620	24	109	208
Total Kjeldahl nitrogen (mg/l)	5.9	<0.5	1.0	208
COD (mg/l)	150	13	46	208
Total phosphorus (mg/l)	3.6	0.002	0.26	208
Lead (mg/l)	0.82	<0.1	0.17	208
Zinc (mg/l)	0.37	0.03	0.12	208

Note: Data for Surrey Downs and Lake Hills combined, from 2/80 through 1/82.
Source: Pitt (ref. 5, from Table 6-1).

TABLE 27 Metallic Priority Pollutants and Cyanide in Stormwater Reported by Metro

Constituents (µg/l)	Max.	Min.	Average	# of Total Storm Samples
Antimony	<3	< 3	< 3	21
Arsenic	37	3	13	21
Beryllium	< 0.3	< 0.3	< 0.3	21
Cadmium	1.9	≤ 0.1	0.7	21
Chromium	19	2	7	21
Copper	46	4	20	19
Lead	460	60	210	21
Mercury	< 0.5	< 0.2	< 0.5	20
Nickel	32	3	11	21
Selenium	< 2	< 2	< 2	21
Silver	0.6	< 0.2	< 0.5	20
Thallium	< 1	< 1	< 1	21
Zinc	250	28	110	21
Cyanides	20	< 5	< 15	12

Note: Data for Surrey Downs and Lake Hills combined.
Source: Galvin and Moore (ref. 2, from Tables 7 and 8).

The USGS (ref. 1, Table 25) analysed 15 samples from the three study areas on May 20, 1980, for dissolved and total recoverable lead. They found that about 25 percent of the total recoverable lead was dissolved with a reported range of about eight to 60 percent dissolved. These total recoverable values are slightly less than the total concentrations reported in Table 27.

The USGS also analysed about 16 of their discreet samples for a wide list of insecticides and herbicides. These data are summarized in Table 28. Only Lindane, Diazinon, Malathion, Dieldrin, and 2,4-D were detected in more than one-half of the samples tested by the USGS. Endosulfan, Silvex, and 2,4,5-T were found in about one-third of the samples submitted. Many of the insecticides and herbicides shown on Table 28 were not detected in any of the samples or were only detected in one of the 16 samples.

The organic priority pollutant analyses of 21 total storm flow-weighted samples are shown on Table 29 (ref. 2, Table 20). None of the organic priority pollutants detected by METRO were found in more than 25 percent of the samples submitted. Of the 111 organic priority pollutants, only 19 were detected at least once in the METRO stormwater sample analyses. Except for one value (a pentachlorophenol value of 115 ug/L) they were all very close to the detection limits. The 21 flow-weighted composite samples were obtained from both Surrey Downs and the Lake Hills stations between August, 1980, and January of 1982. Organic priority pollutants were found in only ten of these samples. All of the seven pesticides detected by METRO exceeded the chronic criteria and three also exceeded the acute criteria at least once. However, these criteria are established for receiving water conditions and not for undiluted stormwaters. They do indicate the potential problem associated with low level organic pollutants entering receiving waters from stormwater runoff. METRO (ref. 2, pp.3-20 through 3-21) also found that almost all (71 to 96 percent) of the total extractable organics in urban runoff was associated with the particulate material.

The USGS (ref. 6, Table 31 and pp.111-114) also examined stormwater suspended sediment size distributions. Table 30 summarizes this data from four to seven samples that were analysed from the three USGS monitoring locations. These analyses showed that 64 percent of the suspended material in stormwater was associated with particle sizes smaller than 62 microns. Only about ten percent of the stormwater suspended particles had sizes greater than 250 microns. These data are very important because they indicate the limited washoff of particulates from various areas within the catchment and also indicate the potential for settleable solids to accumulate in the catchbasins, sewerage, and receiving waters. Again, the USGS found high concentrations of suspended solids during high discharges. About half of the suspended solids concentration variations at Lake Hills and Surrey Downs was found to be caused by flow variations. High suspended solids concentrations were also observed by the USGS near the beginning of some of the storms. These high initial suspended solids concentrations were typically unique in that they had much higher concentrations than would be expected from their discharges. These periods of disproportionately high concentrations of suspended solids were of relatively short durations and the loads during these parts of the storms were not significant parts of the total storm loads.

TABLE 28 Stormwater Insecticide and Herbicide Concentrations Reported by the USGS

Constituent	# of Samples Detected	# of Samples Tested	Detection Limit (μg/l)	Observed Values (μg/l)
Aldrin	1	14	<0.01	0.01
Chlordane	1	15	<0.01	0.1
DDD	1	14	<0.01	0.01
DDE	1	14	<0.01	0.01
DDT	2	15	<0.01	0.01
Dieldrin	7	15	<0.01	0.01 → 0.03, 0.02 median
Endosulfan	5	14	<0.01	0.01 → 0.08, 0.02 median
Endrin	0	14	<0.01	
Heptachlor	0	14	<0.01	
Heptachlor epoxide	2	14	<0.01	0.01
Lindane	14	15	<0.01	0.01 → 0.06, 0.01 median
Mirex	0	14	<0.01	
Methoxychlor	0	14	<0.01	
Naphthalenes, polychlor.	0	12	<0.01	
PCB	1	15	<0.01	0.1
Toxaphene	0	14	<1.	
Diazinon	8	15	<0.01	0.02 → 2.3, 0.12 median
Ethion	0	14	<0.01	
Malathion	11	15	<0.01	0.04 → 4.1, 0.09 median
Methyl parathion	0	14	<0.01	
Methyl trithion	0	14	<0.01	
Parathion	1	14	<0.01	0.12
Total trithion	0	14	<0.01	
2,4-D	10	16	<0.01	0.01 → 3.3, 0.05 median
Silvex	6	16	<0.01	0.01 → 0.40, 0.02 median
2,4,5-T	5	16	<0.01	0.01 → 0.07, 0.02 median

Note: Perthane and 2,4-DP were also analyzed in two samples, but were undetected (<0.01 μg/l).
Surrey Downs, Lake Hills and 148th Ave. S.E. data combined.

Source: Ebbert, Poole, and Payne (ref. 1, from table 23).

TABLE 29 Organic Priority Pollutant Concentrations in Stormwater Reported by Metro

Constituent	# of Samples Detected	# of Total Storm Samples Tested	Observed Values (µg/l)
Pesticides:			
Endosulfan	1	21	0.2
Dieldrin	3	21	0.008 → 0.1, 0.02 median
α-BHC	4	21	0.003 → 0.06, 0.03 median
γ-BHC (Lindane)	5	21	0.006 → 0.9, 0.03 median
δ-BHC	2	21	0.006, 0.007
DDT	1	21	0.35
Heptachlor	1	21	0.01
Aliphatics:			
Trichloromethane	1	21	0.2
Aromatics:			
Benzene	2	21	10, 13
Phenolics:			
Phenol	1	21	3 (expected contaminated)
Pentachlorophenol	4	21	3 → 115, 10 median
Phthalates:			
Di-n-octylphthalate	1	21	0.4
PAHs:			
Fluoranthene	4	21	0.3 → 12, 2 median
Benzo(a)pyrene	2	21	1, 2
3-4 benzofluoranthene	1	21	2
Chrysene	3	21	2 → 3
Phenanthrene	4	21	0.3 → 7, 1 median
Pyrene	4	21	0.3 → 10, 6 median
Benzo(a)anthracene	2	21	1, 3
Benzo(k)fluoranthene	1	21	4
Anthracene	1	21	1

Note: Data for Lake Hills and Surrey Downs combined.
Source: Galvin and Moore (ref. 2, from table 20).

Table 30 Stormwater Suspended Sediment Size Distributions

Suspended Sediment Sieve Diameter (microns)	Percent in Size Range
> 1,000	0.5%
500 → 1,000	3.5
250 → 500	7.0
125 → 250	9.3
62 → 125	15.7
< 62	64.0
total	100.0%

Note: based on four to seven sample analyzes from Lake Hills, Surrey Downs, and 148th Ave. S.E.

Source: Prych and Ebbert (ref. 6, from Table 31).

The City of Bellevue study (ref. 5, Table 6-4) also examined the base flow quality at Surrey Downs and Lake Hills. The runoff water quality at Bellevue was much better than observed in most other locations. The base flow quality, on the other hand, was found to be worse than expected. This was probably because the study basins were completely urbanized and the base flows were percolated urban sheet flow waters from previous storms that were draining out of the surface soils. In basins with undeveloped upstream areas, the base flow would originate mostly from the non-urbanized upper reaches and would have much better quality. The data shown in Table 31 were collected from 26 24-hour composite samples collected from both Surrey Downs and Lake Hills during the project duration. A single sample was obtained from each location about once every month or two.

The USGS and the City of Bellevue both calculated stormwater runoff yields for the different test areas. Table 32 (ref. 1, Table 10) shows the USGS estimates of annual runoff yields in Surrey Downs, Lake Hills, and 148th Avenue S.E. for the constituents that they monitored. The USGS total solids values were calculated by adding the suspended and dissolved solids values. The dissolved solids concentrations, however, were estimated based on specific conductance measurements. These estimates of annual yield are based on the actual flow volumes monitored for almost the complete study period, but are based on quality measurements from a limited number of storms. A model simulation was then used to estimate the yields of the storms that were not sampled.

Table 33 presents the data from the City of Bellevue study (ref. 5, Table 6-5). The City of Bellevue analysed total storm flow-weighted composite samples for almost all runoff events that occurred at Surrey Downs and Lake Hills during the two-year study period. The continuous USGS storm flow data was also used in calculating these annual base flow and stormwater runoff mass yield estimates. There was an apparent difference between the runoff discharges in Lake Hills and Surrey Downs when expressed on a unit area basis. However, the total annual runoff plus base flow discharges from the two basins were quite similar. This implies that a much larger fraction of the total urban runoff in Surrey Downs occurred as base flow between rain events. The runoff events in Lake Hills were more sharply defined; the base flow was a much smaller fraction of the total urban runoff mass yields.

A comparison of the annual yields and concentrations of selected storms from the USGS and the City of Bellevue studies are summarized in Table 34. The ratios of USGS concentrations to Bellevue concentrations for the different constituents varied from about 0.66 for total phosphorus to about 1.15 for COD. Most of the concentration ratios are less than 1.0, indicating higher Bellevue-reported stormwater concentrations for these eight storm events. These eight events were simultaneously monitored with approximately equal beginning and ending times in the two basins at various times during the study period. The comparison of the annual stormwater runoff yields, however, shows that the USGS estimates were substantially larger than the measurements conducted by the City of Bellevue. If the base flow yields shown on Table 33 are added to the stormwater runoff yields from the City of Bellevue studies, then the annual urban area discharges are much closer.

Determining the relative importance of different urban areas in contributing urban runoff pollutants to the outfall is based on an understanding of the natural and man-made processes and supplemented by the

Table 31 Baseflow Water Quality Reported by the City of Bellevue

Constituent, mg/l unless otherwise noted	Max.	Min.	Average	Number of 24 hr. Composite Samples
Specific conductance, μmhos/cm	430	138	260	18
Total Solids	326	108	202	26
COD	67	6.8	23	26
Total Kjeldahl nitrogen	2.4	0.20	0.8	26
Total phosphorus	1.2	0.027	0.16	26
Lead	0.1	< 0.1	< 0.1	26
Zinc	0.47	0.026	0.09	26

Note: Surrey Downs and Lake Hills data combined
Source: Pitt (ref. 5, Table 6-4).

TABLE 32 Annual Stormwater Runoff Mass Yields Reported by the USGS (based on a model simulation to estimate yields of storms not sampled) (kg/ha/yr).

Constituent	Surrey Downs	Lake Hills	148th Ave. SE
Total solids (1)	330	370	1200
Dissolved solids (2)	110	87	290
Suspended solids	220	280	870
COD	160	180	690
BOD_5	14	15	74
BOD - ultimate	50	63	175
Total Kjeldahl nitrogen	3.9	3.9	10
Dissolved Kjeldahl nitrogen	2.2	2.3	5.9
Ammonia	0.41	0.48	1.8
Nitrite plus nitrate	0.91	0.69	2.3
Total phosphorous	0.48	0.76	1.4
Dissolved phosphorous	0.19	0.32	0.39
Lead, recoverable	0.43	0.67	2.0
Total organic carbon	32	29	94
Dissolved organic carbon	24	20	68
Suspended organic carbon	8.3	9.1	26
Fecal coliforms bacteria (10^9/ha/yr)	60	83	98

(1) total solids was calculated by adding suspended and dissolved solids

(2) dissolved solids was estimated based on specific conductance measurements

Source: Ebbert, Poole, and Payne (ref. 1, from Table 10).

TABLE 33 Annual Baseflow and Stormwater Runoff Mass Yields Reported by the City of Bellevue (based on almost complete storm flow-weighted composite concentration records and continuous USGS flow records) (kg/ha/yr)

Constituent	Surrey Downs			Lake Hills		
	base flow	storm runoff	total	base flow	storm runoff	total
Total solids	110	205	315	76	280	360
COD	11	90	100	9.9	110	120
Total Kjeldahl nitrogen	0.60	1.8	2.4	0.20	2.7	2.9
Total phosphorus	0.11	0.40	0.51	0.04	0.69	0.73
Lead	~0.03	0.26	0.29	~0.02	0.45	0.47
Zinc	0.060	0.24	0.30	0.027	0.31	0.34

Source: Pitt (ref. 5, Table 6-5).

TABLE 34 Ratio of USGS to Bellevue Reported Stormwater Concentrations and Annual Mass Yields.

	Based on 8 storm event - mean concentrations or values			Based on annual yields	
	Max.	Min.	Average	Surrey Downs	Lake Hills
Rainfall	1.00	0.69	0.88	--	--
Runoff	1.03	0.72	0.89	--	--
Total Solids (1)	1.46	0.66	0.89	1.6	1.3
COD	1.43	0.89	1.15	1.8	1.6
Total Kjeldahl N	1.22	0.50	0.97	2.2	1.4
Total phosphorous	1.11	0.40	0.66	1.2	1.1

(1) The USGS calculated total solids based on dissolved solids (estimated from specific conductance valves) plus suspended solids data.

Source: from Prych and Ebbert (ref. 6 Table 26), Ebbert, Poole, and Payne (ref. 1 Table 10), and Pitt (ref. 5 Table 6-5).

limited available data for Bellevue. The variations in sheet flow quality from the source areas during runoff events and the concentrations of pollutants from each source differs from the contributions of runoff flows. The City of Bellevue study (ref. 5, p.2-3 and Figure 6-9 through 6-14) made estimates of the pollutant contributions from the different source areas. Table 35 summarizes these estimates based on the previously discussed contribution of urban runoff flows from different source areas. Estimates of sheet flow quality from the different source areas were made based on limited local data and slightly more data from other locations. Figures 8 and 9 show examples of how the importance of the different source areas changed for different types of rain. During very small rains most of the runoff, and therefore pollutant discharges, were associated with the directly connected impervious areas. As the rain total increased (greater than about 2.5 mm for Bellevue), then the pervious areas become much more important. These patterns varied significantly for different areas depending on the rain characteristics and land uses. It was estimated that for most rain events total solids originated mostly from the back and front yards in the test areas, and street surfaces contributed only a small fraction of the total solids urban runoff discharge. Street surfaces, however, were expected to make up most of the lead, zinc, and COD concentrations in urban runoff. Phosphates and total Kjeldahl nitrogen were mostly contributed from street surfaces, driveways, and parking lots combined. Front and back yards made up slightly less than half of these nutrient contributions to the outfall. It was noted that zinc contributions from rooftops made up about one-fourth of the total zinc discharges. These zinc rooftop sources were expected to be associated with galvanized metal rain gutters and downspouts.

The specific contributions of pollutants from these different source areas are very important when designing source area control measures. As an example, street cleaning cannot be expected to significantly improve urban runoff loadings or concentrations of those constituents that are contributed from non-street areas. If the available street surface particulate loadings could be reduced by half, then many of the constituents may be reduced by a maximum of 25 percent at the outfall. Total solids discharges, however, would be expected to be improved by less than five percent. The next subsection addresses the availability of street dirt material to urban runoff.

There are many individual problems associated with source area contributions. Pedersen (p.69) noted that the downstream Kelsey Creek monitoring station was susceptible to dumps of material made in upstream storm drains. A common occurrence was the heavy deposition of silt-like material from an upstream cement plant during cleanup operations.

4. Street Dirt Contributions to Urban Runoff Discharges

The City of Bellevue examined street dirt loadings in the three urban runoff test areas during the two-year period of study (ref. 5, Section 7). By the end of January, 1982, about 600 street surface accumulation samples were collected from the test areas in Bellevue. The Surrey Downs area was divided into three separate areas with 198 samples collected in the main Surrey Downs area, 104 collected from the 108th Street subarea, and 52 collected from the Westwood Homes Road subarea. In addition, 220 samples were obtained in the Lake Hills basin and 28 were collected in the 148th Avenue S.E. area. The Surrey Downs and Lake Hills samples were collected during about two years,

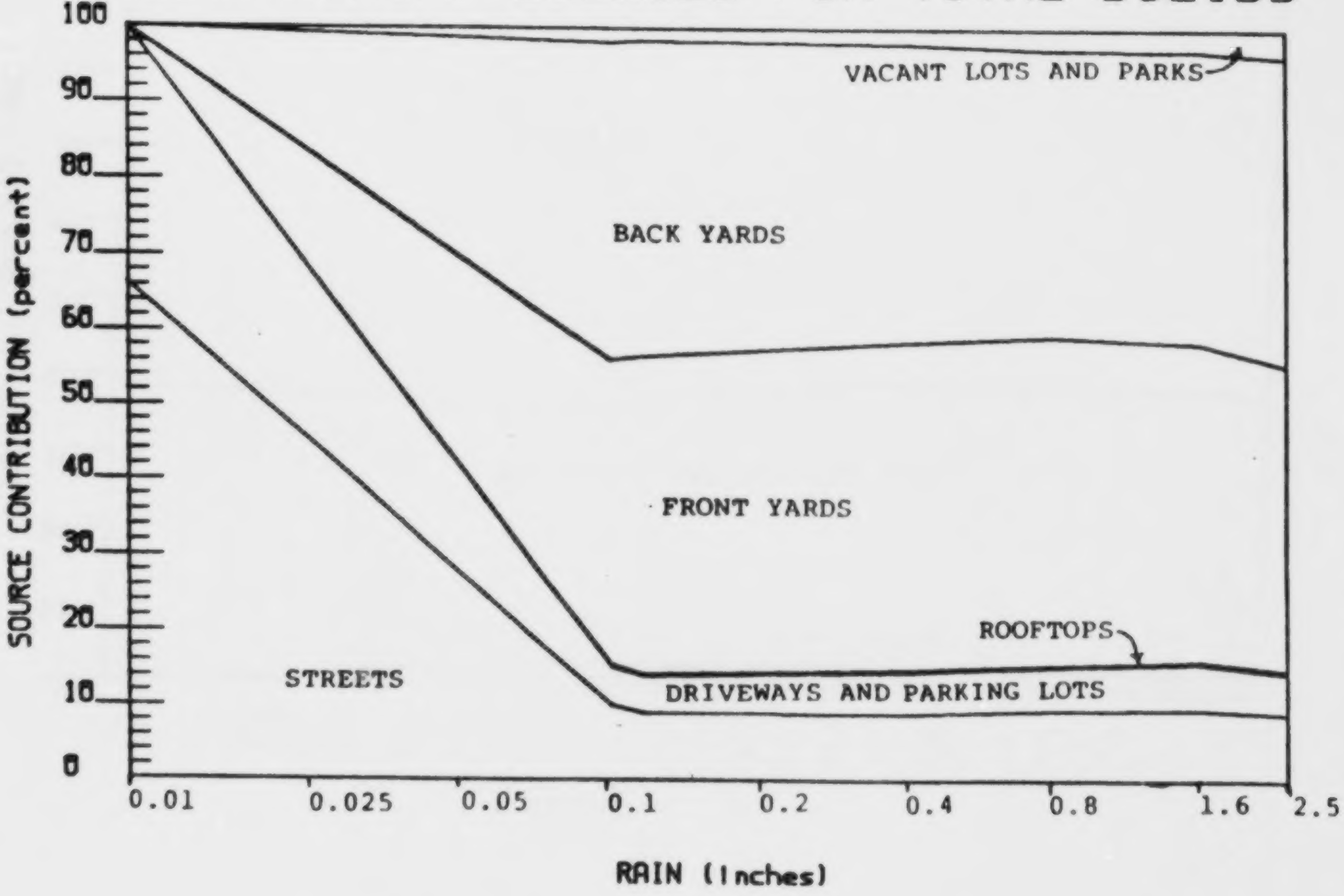
TABLE 35 Source Areas for Urban Runoff Pollutants
(for 2.5 to to 65 mm rains).

(Approx.) Source Area	Percent Contributions from Source Areas					
	Total Solids	COD	Phosphates	Total Kjeldahl Nitrogen	Lead	Zinc
Streets	9 %	45 %	32 %	31 %	60 %	44 %
Driveways and parking lots	6	27	21	20	37	28
Rooftops	< 1	3	5	10	< 1	24
Front yards	44	13	22	19	< 1	2
Back yards	39	12	20	20	< 1	2
Vacant lots and parks	2	< 1	< 1	< 1	< 1	< 1

Source: Pitt (ref. 5, Figures 6-9 through 6-14).

FIGURE 8

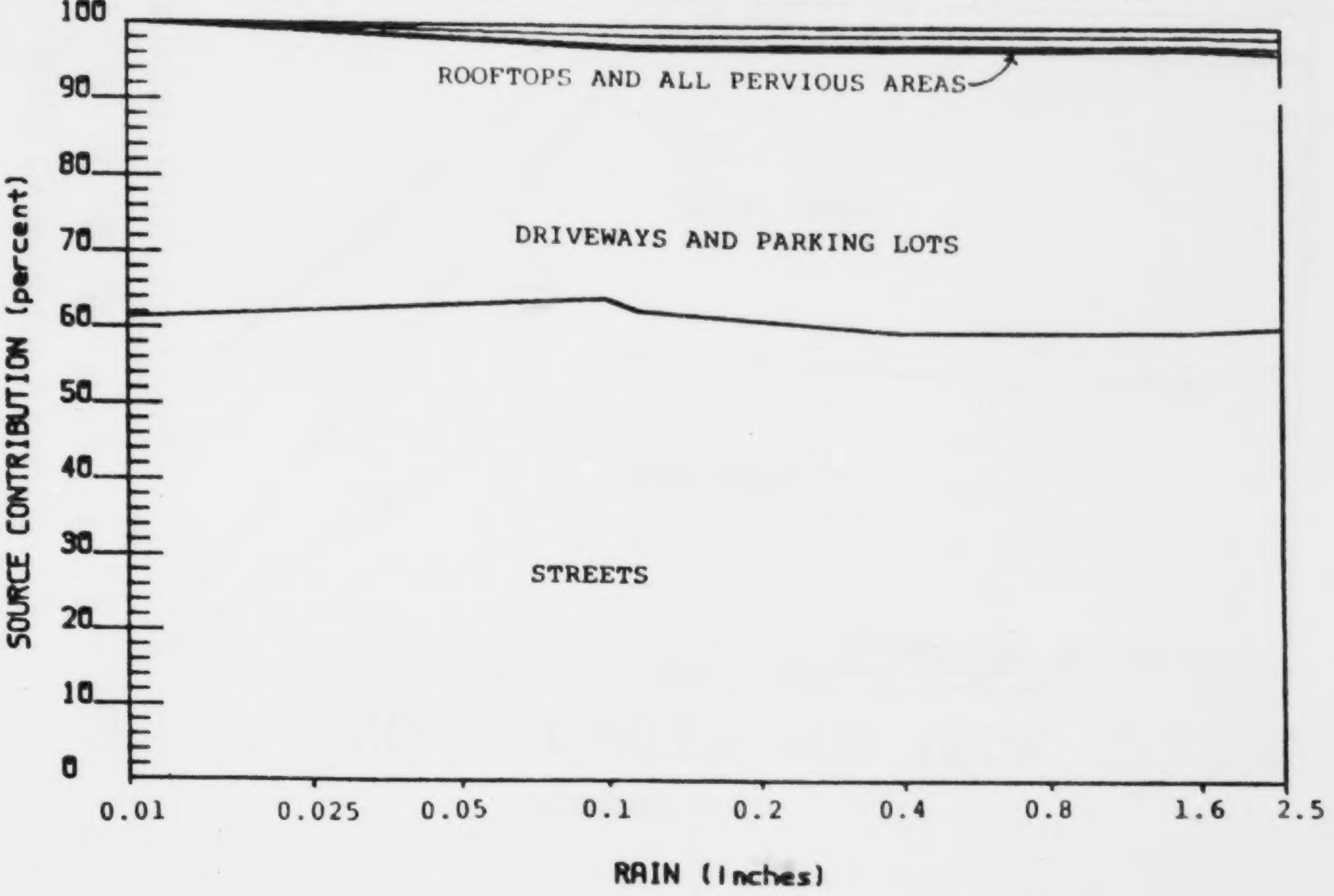
URBAN RUNOFF SOURCES FOR TOTAL SOLIDS



Source: Pitt (ref. 5, figure 6-9).

FIGURE 9

URBAN RUNOFF SOURCES FOR LEAD



Source: Pitt (ref. 5, figure 6-13).

while the 148th Avenue S.E. samples were collected only during the last eight months of the project. The observed street surface particulate loading values for each sample were plotted to observe changes in street surface loadings with time and to determine the initial deposition and long-term accumulation rates.

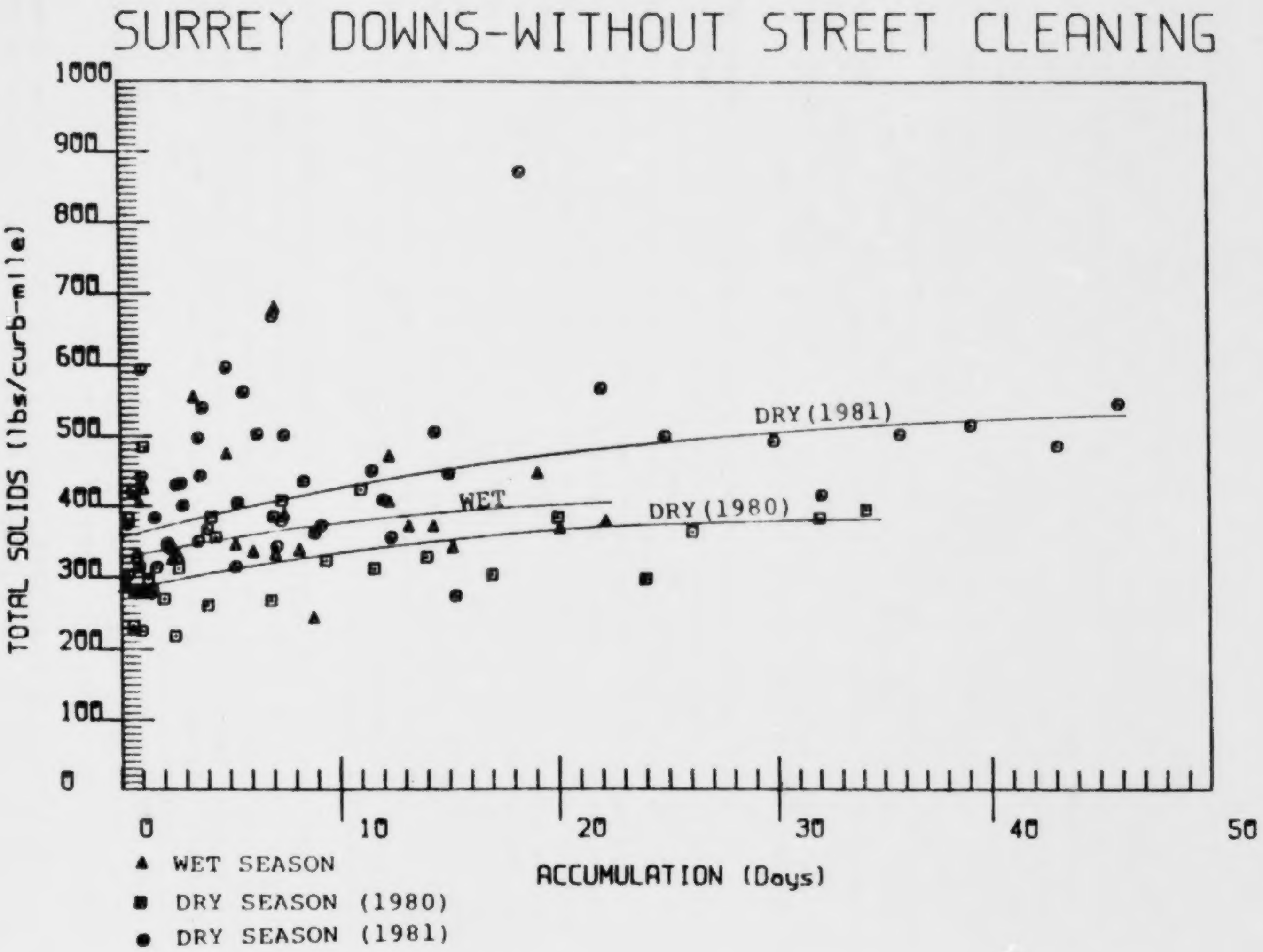
Figure 10 shows an example plot for the Surrey Downs Basin during periods without street cleaning. The deposition rate is the initial accumulation rate which occurs over the first several days of exposure after a significant rain or street cleaning. The two factors which affect the accumulation rate are the deposition rate and the removal rate. The accumulation rate equals the deposition rate minus the removal rate. The deposition rate is a function of various characteristics of the area; especially, climate, land use, traffic, and street surface texture conditions. The removal of pollutants can be accomplished either by street cleaning, traffic-induced turbulence, or naturally by winds or rains. The difference between the accumulation and deposition rates at any time is assumed to be caused by material blown from the street surface by wind or the traffic-induced turbulence. This material can remain suspended in the air, but most of it settles to the ground within about ten meters of the roadway. As shown in Figure 10, there is appreciable scatter in this data, especially for the small accumulation periods. Much of this scatter is because of the relatively low street surface loadings observed in Bellevue.

The accumulation curves shown on these figures were determined using a combination of least squares, multiple regression curve fitting techniques, and Student's t analyses. The accumulation data was log-transformed before the curve fitting techniques were used to get even representation of loadings over the range of the accumulation dependent variable. The accumulation information was also analysed by stratifying the data into relatively small accumulation periods. Significant differences of the loadings within these periods were identified using Student's t analyses. In almost all cases the 1981 dry period had street surface loading values significantly greater than the 1980 dry period during the time of no street cleaning. The wet season data is not separated for analysis by year because most of that data was collected during continuous months during the fall and winter of 1980 and 1981. The 1980 and 1981 dry seasons, however, were separated by the five-month wet season. It is not known why the 1981 dry season loadings were significantly greater than the 1980 dry period loadings.

Each of these 600 street surface samples were separated into eight different particle sizes. Figure 11 shows the size distributions for each of these five areas during the dry seasons. These size distributions show that the smallest particle sizes account for only a small fraction of the total material. This was especially true during the wet season when the rains were most effective in removing the smallest particles. During the dry season the larger particle sizes accounted for relatively small fractions of the total solids weight also. Most of the street surface particulates were associated with particles in the size range of 125 to 1000 microns.

The City of Bellevue (ref. 5, p.2-4) noted that the Bellevue street surfaces included in the test were relatively clean when compared to other locations throughout the country. This difference is expected to be mostly due to the frequent rains that occur in Bellevue. The initial accumulation rates (assumed to be equal to the deposition rates) in the test areas was

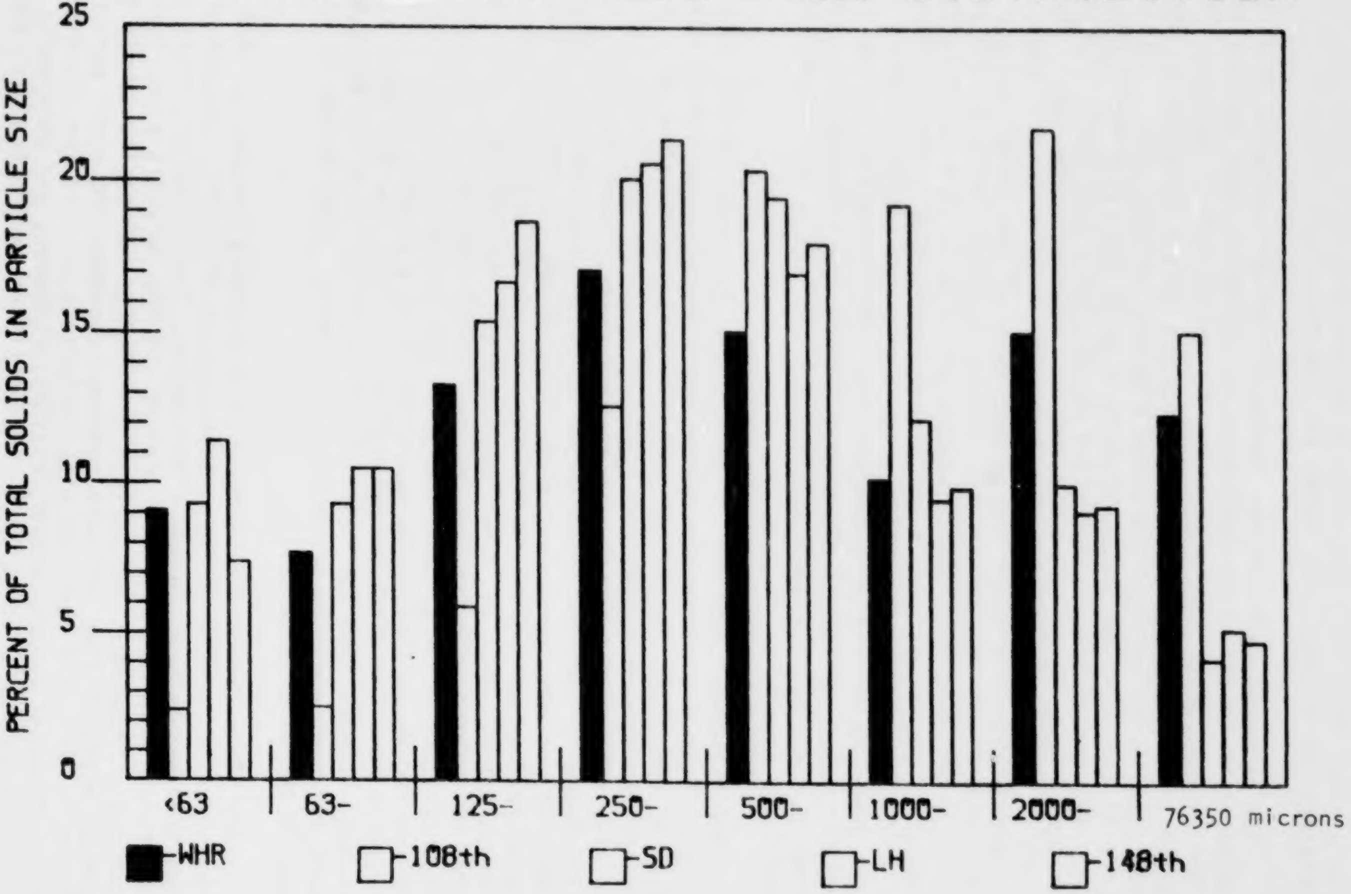
FIGURE 10



Source: Pitt (ref. 5, figure 7-3)

FIGURE 11

DRY SEASON PARTICLE SIZE DISTRIBUTION



Source: Pitt (ref. 5, figure 7-5).

estimated to vary between one and six (with an average of about three) grams/curb-meter/day. This is comparable to accumulation rates observed in other locations for smooth streets in good condition. The accumulation rates may be several times these values for streets in poor condition. The Bellevue streets never have an opportunity to become extremely dirty due to the moderately low accumulation rates and the relatively frequent rains.

The frequent rains do not remove all of this material from the streets. From about 50 to 100 grams/curb-meter of street surface particulates remain on the streets after storms of about six mm of rain or greater. This initial loading value is similar to initial loading values observed at other locations. These loading values would be much greater for streets in poor condition than for the smooth streets in good condition monitored in this study. The amount of street surface particulates that can be removed from Bellevue streets by rains is limited to a fairly narrow range. The washoff of street surface particulates is described in greater detail later. In brief, infrequent large rains can remove much more of the street surface particulates than the more common smaller rains in Bellevue and small particles are much more easily washed off streets than large particles. The texture of the street itself has a tendency to trap a certain amount of particulates. As discussed in Section C, typical street cleaning equipment also cannot remove the particulates that are "protected" by the street texture. Rains and street cleaning equipment are effective in removing the street surface particulates only above these levels (of between 50 and 100 grams/curb-meter).

The Bellevue study (ref.5, Section 7) also examined the chemical characteristics associated with the particulates in different size ranges. Table 36 summarizes these Bellevue observations. The chemical characteristics were not unusual when compared to other locations throughout the U.S. When the five different substudy area characteristics were examined, the largest differences in chemical characteristics were noted for lead especially when comparing Westwood Homes Road with 148th Avenue S.E. The Lake Hills lead concentrations were also greater than the Surrey Downs main basin lead concentrations. This was probably because of the smaller median particle sizes associated with the Lake Hills samples. Because of the much greater concentrations of lead associated with the smaller particle sizes, the smaller median particle size would result in a greater total solids lead concentration. The total solids median particle size for 108th Street dirt was much greater than the total solids particle sizes for the other test areas and indicated the presence of many more larger particles on the road than in the other test basins.

The 148th Avenue S.E. samples were probably greater in lead concentration because of the greater amount of traffic concentrated on that road than was typical in the other basins. Composites of street surface particulate samples were made from all of the particle sizes for each of the test areas throughout the project period. Each composite sample represented several weeks of time and were combined representing eight particle sizes. Figure 12 shows the particle size variations of lead for the different study areas. Chemical oxygen demand, Kjeldahl nitrogen, and phosphorus concentrations all showed high concentrations associated with the smallest particle sizes, small concentrations with the intermediate sizes, and high concentrations with the larger sizes. This was probably because of the presence of leaves and other organic material associated with the largest

TABLE 36 Street Dirt Chemical Characteristics

Whole Sample Strength (mg constituent/kg total solids)

Constituent	Surrey Downs			Lake Hills	148th Ave. SE
	Main Basin	108th St.	Westwood Homes Rd		
COD	145,000	51,000	240,000	190,000	100,000
TKN	1600	460	2200	2300	850
Total phos.	580	510	590	640	460
Lead	750	460	190	1200	1500
Zinc	170	130	90	230	190

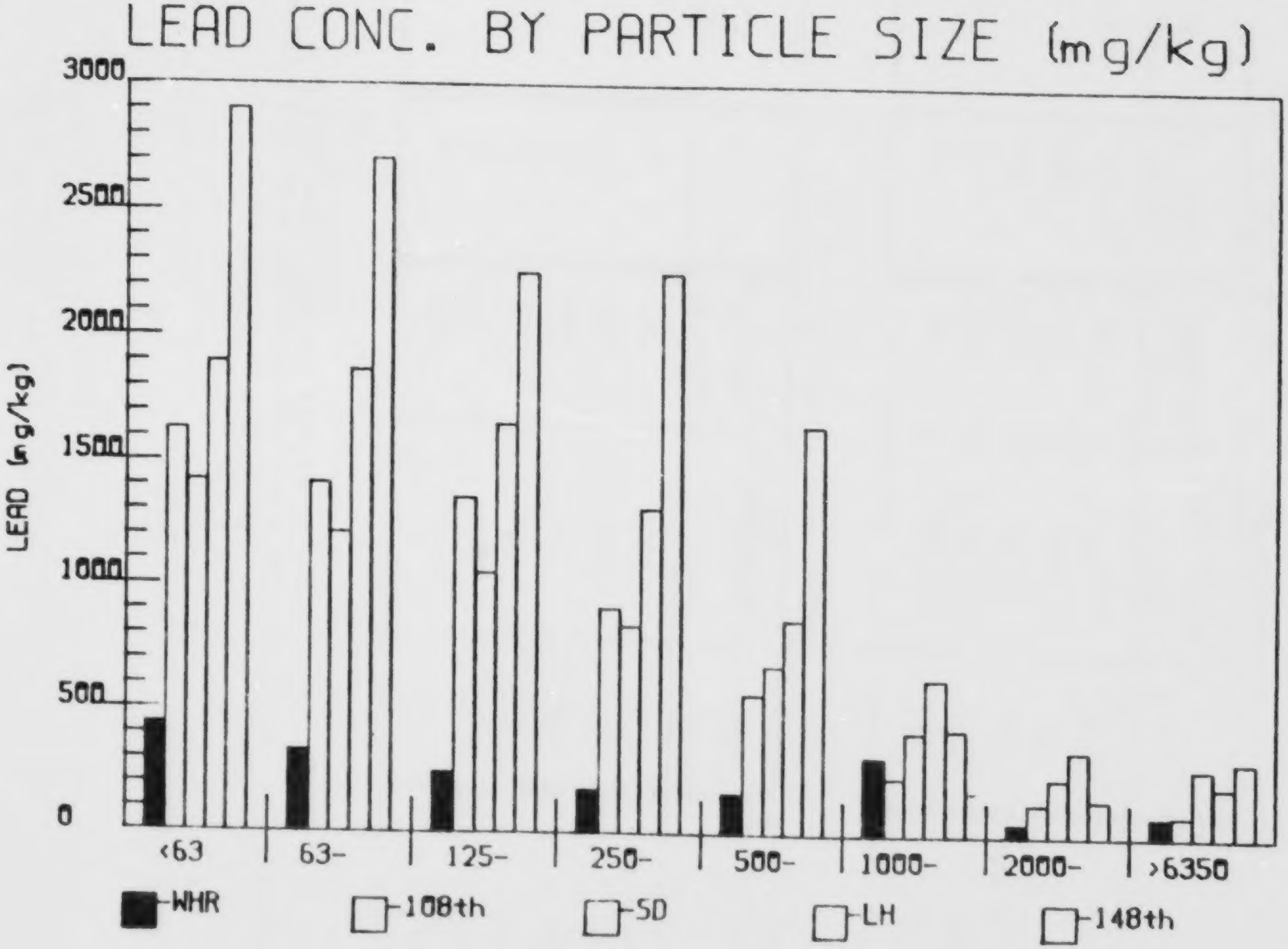
Median Particle Size (microns)(1)

Constituent	Surrey Downs			Lake Hills	148th Ave. SE
	Main Basin	108th St.	Westwood Homes Rd		
Total solids	520	1400	840	420	610
COD	810	1700	2000	730	1100
TKN	420	780	780	400	770
Total phos.	670	1900	890	430	260
Lead	290	440	420	230	320
Zinc	350	1200	640	260	360

(1) half of the constituents (by weight) are associated with particles greater than these sizes, while half are associated with particles smaller than these sizes.

Source: Pitt (ref. 5, table 7-5).

FIGURE 12



LEAD CONC. BY PARTICLE SIZE (mg/kg)

Source: Pitt (ref. 5, figure 7-7).

particle sizes which would have relatively high nutrient concentrations. The lead and zinc concentrations, however, showed typical particle size distributions for heavy metals with the highest concentrations associated with the smallest particle sizes. The Figure 12 values show that the Westwood Homes Road and the Surrey Downs basin typically had the smallest lead concentrations of any of the sizes. This was probably because of the small amount of traffic on that road. 148th Avenue S.E., in contrast, is a well-traveled street and showed very high lead concentrations especially in the smallest particle sizes.

The street dirt chemical characteristics were separated into wet and dry seasons for the different basins and were compared using Student's t analyses. In most cases, there were no significant differences observed between the different seasons. However, many of the very largest particle sizes did show significant differences between the wet and dry seasons; about half of the particle sizes for lead showed significant differences.

The Seattle METRO project (ref.2, p.3-41) also examined heavy metals in the street surface particulate samples collected by the Bellevue sampling team. Table 37 presents the results of metallic priority pollutants and cyanides found in 12 different samples that were analysed by METRO. All of the inorganic priority pollutants, except selenium, were detected in the street dirt. The most abundant metals were lead, zinc, chromium, copper, nickel, arsenic, cadmium, and beryllium. METRO did not find any clear differences between metal concentrations in the two residential basins or when these residential basin street dirt characteristics were compared with commercial and industrial samples that were collected in Seattle. They also found that the concentrations of metals were greatest in the finer size particles but these fine particles accounted for only a small portion of the total solids loadings on the street surfaces. When these metallic priority pollutant analyses were compared with similar analyses conducted elsewhere in the U.S., the Bellevue concentrations tended to be quite low (except for arsenic).

Seattle METRO (ref. 2, p.3-62) also analysed street dirt samples for organic priority pollutants. Table 38 summarizes the positive observations of these analyses. Of the 111 organic priority pollutants, only about 30 were detected in the street dirt samples. At least one compound from each of the nine organic toxic pollutant groups (except PCBs) appeared in the 14 samples that were analysed. Seven of these samples were from the Surrey Downs and Lake Hills basins while the other samples were collected in Seattle commercial and industrial sites. The polycyclic aromatic hydrocarbons (PAHs) were the most common (accounting for the four most frequent organic priority pollutants detected). Phthalate esthers were also common and accounted for several of the top ten organics detected. Two of the PAHs (fluoranthene and phenanthrene) were found in all of the street dirt samples. Several of the compounds had concentrations greater than one part per million (one mg constituent/kg total solids) while one phthalate was recorded as great as 35 ppm. It was also noted that most of the organic priority pollutants were associated with the finest particle size fractions.

When the analyses for the different land uses were compared it is interesting to note that the pesticides were only found in the residential street surface samples and were not found in the arterial (148th Avenue S.E.) sample, or the commercial and industrial Seattle street dirt samples. The

TABLE 37 Metallic Priority Pollutants and Cyanides in Street Dirt

Constituents	mg constituent/kg total solids			detected in samples	# of samples analyzed
	Max.	Min.	Average		
Antimony	2.0	< 0.2	0.8	8	12
Arsenic	47	11	25	12	12
Beryllium	0.38	0.17	0.3	12	12
Cadmium	2.0	0.6	1	12	12
Chromium	230	20	97	12	12
Copper	260	31	93	12	12
Lead	1300	90	520	12	12
Mercury	0.18	< 0.05	0.06	9	12
Nickel	44	20	32	12	12
Selenium	< 3	< 0.6	< 3	0	12
Silver	0.5	0.01 (< 0.5)	0.1	6	12
Thallium	< 1	< 0.2	< 1	3	12
Zinc	970	110	310	12	12
Cyanides	0.7	< 0.05	0.2	8	12

Note: Data combined for Surrey Downs (main basin) and Lake hills

Source: Galvin and Moore (ref. 2, table 31)

Table 38 Organic Priority Pollutants Detected in Street Dirt

Constituents:	# of samples detected	# of samples analyzed	observed values (mg const./ kg total solids)
Pesticides:			
α-BHC	2	7	0.010, 0.018
γ-BHC (Lindane)	2	7	0.006, 0.043
DDD	1	7	0.005
Heptachlor	1	7	0.048
Halogenated Aliphatics:			
Trichloromethane	4	7	0.004→0.015; 0.005 median
Tetrachloroethene	2	7	0.016, 0.032
4-Chlorophenyl phenyl ether	1	7	0.24
Monocyclic Aromatics:			
Hexachlorobenzene	1	7	2.0
Ethylbenzene	3	7	0.005→0.025; 0.005 median
Toluene	3	7	0.004→0.008; 0.005 median
Phenolics:			
Phenol	3	7	0.08→0.47; 0.1 median
Pentachlorophenol	2	7	0.12, 3.4
2,4-Dimethylphenol	2	7	0.01, 0.03
4-Nitrophenol	1	7	0.11
Phthalate Esters:			
Dimethyl phthalate	1	7	0.78
Diethyl phthalate	3	7	0.16→0.89; 0.18 median
Di-n-butyl phthalate	3	7	0.49→2.4; 0.52 median
Di-n-octyl phthalate	1	7	0.97
Butyl-benzyl phthalate	4	7	0.22→35; 0.8 median
Bis-2 ethylhexyl phthalate	3	7	11→24; 20 median
PAHS:			
Acenaphthene	1	7	0.16
Anthracene	2	7	0.24, 0.29
Benzo(a)anthracene	1	7	0.66
Benzo(k)fluoranthene	3	7	0.28→1.4; 1.4 median
Benzo(a)pyrene	2	7	0.08→0.64
Chrysene	5	7	0.21→2.0; 1.0 median
Fluorene	1	7	0.2
Phenathrene	7	7	0.18→1.9; 0.88 median
Pyrene	6	7	0.32→2.4; 1.4 median
Fluoranthene	7	7	0.74→2.6; 1.2 median

Note: Date combined for Surrey Downs (main basin) and Lake Hills.

Source: Galvin and Moore (ref.2, Table 41).

halogenated aliphathics, monocyclic aromatics, phenolics, and phthalate esthers were very common in the residential samples but were only infrequently found in the other samples. The industrial sample, however, periodically had very high concentrations of some of the constituents.

Almost twice as many organic priority pollutants were found in the street dirt as stormwater (ref.2, p.3-63). Nine of the PAHs in street dirt were also found in the stormwater, but only one of the six phthalates was detected in the stormwater (but it was one that was not frequently found at high concentrations in the street dirt). The compounds found with the highest frequencies and concentrations in the street dirt tended to be the same as those found in the stormwater. Dilution of street surface particulates by the water and particulates from other source areas probably accounts for the low number of the detectable organics in the stormwater.

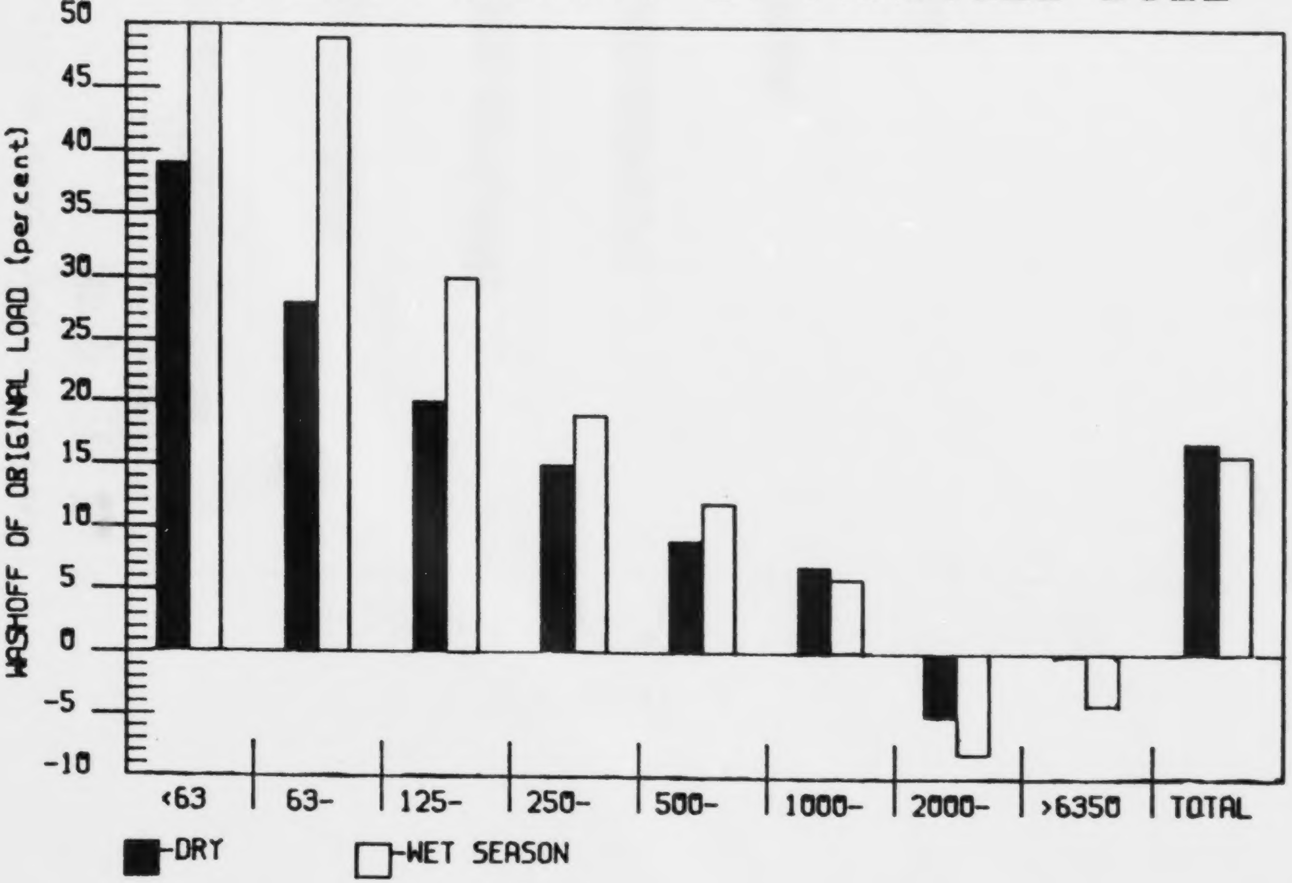
The contribution of street surface particulates to runoff water is dependent on the ability of the rain to loosen and wash off these particulates from the street surface. About 25 pairs of street surface loading values were obtained during the two-year project period that were within a day or two of either side of rains. These before and after rain loading values were compared using Student's t analyses to identify significant differences associated with these rains. In about half of the cases, the loadings on the streets after the rains were significantly different for the dry versus the wet seasons. Much of this difference may be due to the characteristics of the rains occurring in these two seasons. During the dry season in Lake Hills, the before storm loadings were about 90 to 110 grams/curb-meter and there was a significant difference between the residual loadings after the different street cleaning tests versus after the rain. The streets after cleaning were about 15 grams/curb-meter cleaner than after the rains. During the wet season, this difference was reduced to about six grams/curb-meter, but the difference was not significant. During the wet season in Lake Hills the street loadings after street cleaning were about five to six grams/curb-meter cleaner than before the rains.

Figure 13 shows the percentage washoff of the street surface particulates in Lake Hills for both dry and wet seasons. The initial loadings were significantly greater than the residual loadings for particle sizes smaller than about 500 microns in all cases. The smallest particle sizes had the greatest significant washoffs while particle sizes greater than about 500 microns had lower significant washoff values. In the smallest particle sizes the washoffs varied from about 40 to 50 percent while increases were found in street loadings for the larger particle sizes. The overall net loading reduction averaged about 16 percent. This difference in loading was the minimum amount of material that was removed by the rains. It was possible that more material was removed during the rain events and additional material was deposited on the street before the completion of the rains.

Figure 14 shows the size distribution of the material that washed off the streets. Most of the material that washed off the street surfaces occurred in particle sizes less than about 125 microns. Only about ten percent of the washoff material was greater than about 500 microns in size. The largest particle sizes were notably absent from the washoff material. A total of about eight and one-half to ten grams/curb-meter were removed from the street surfaces during the rains with about four to six grams/curb-meter of this material in particle sizes smaller than 125 microns.

FIGURE 13

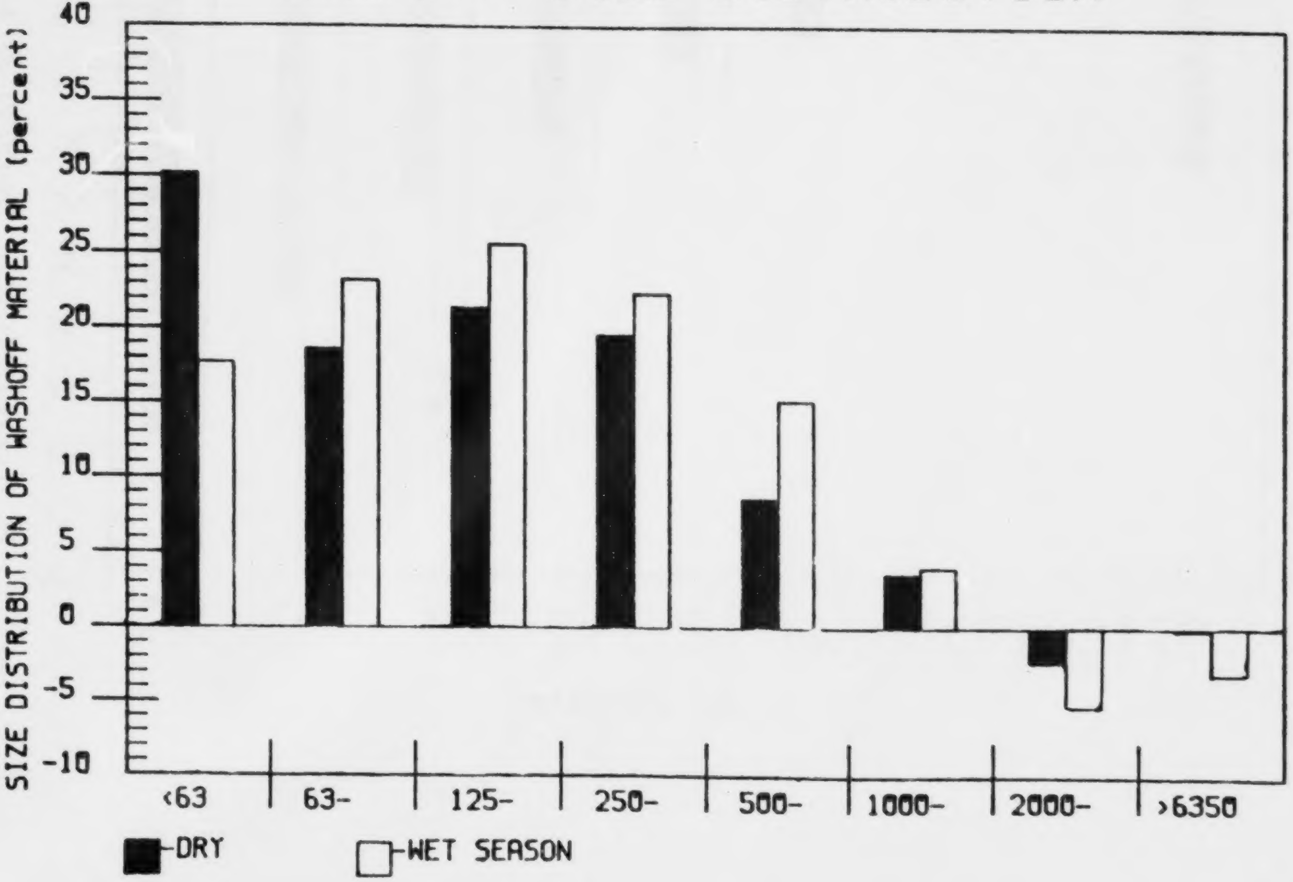
PERCENT WASHOFF BY PARTICLE SIZE



Source: Pitt (ref. 5, figure 9-5).

FIGURE 14

WASHOFF SIZE DISTRIBUTION



Source: Pitt (ref. 5, figure 9-6).

The washoff of street surface particulates associated with the various pollutants was also calculated. For all of the sites, about 14 percent of the total solids were removed by rains observed during these tests. This percentage is about the same or slightly less for COD and total phosphorus while it is slightly more for total Kjeldahl nitrogen and zinc. The washoff percentage is substantially greater for lead (about 21 percent) because of the greater abundance of lead found in the smaller particle sizes. The 108th Street area had much smaller washoffs than any of the other sites (about half the average removals of the other sites) probably because of the greater abundance of the larger size particles on that street. Westwood Homes Road also had smaller washoffs, again because of the larger particles found there.

Not all of the street dirt that accumulated contributed to the urban runoff discharges. Only about 14 percent of the total solids on the street at the time of the rain is washed off. Some of the washed off street dirt accumulates in the sewerage or the catchbasins for indefinite periods of time. The 14 percent value noted above considers differences in loadings observed on the street and not at the end of the pipe. Some of the street surface particulates are also lost to the air due to fugitive dust emissions caused by winds or traffic-induced turbulence. These particulates settle out on adjacent areas while the finer particulates can remain suspended for some time. The amount of street dirt particulates that are lost to the air as fugitive emissions are quite small for the Bellevue area when compared to more arid areas. The short interevent periods do not allow the street surface particulate loadings to become very large and exposed to the winds. The amount of material lost to the air is calculated by considering the deposition rate minus the accumulation rate. As the interevent period increases (to greater than four or five days) the amount of material lost to the air can become important. These atmospheric losses do not become very large until after about ten to 20 days of accumulation which would be quite rare for Bellevue and only occur several times a year during the dry season.

Table 39 (ref.5, Table 11-3) summarizes the approximate annual street dirt accumulations and washoff values and the amount lost to air for the Surrey Downs and Lake Hills sites. In many cases the amounts involved are substantially greater for Lake Hills than Surrey Downs. The reason for these greater street dirt accumulations in Lake Hills is not known but possibly associated with slightly rougher street surface textures or somewhat poorer street surface conditions having more cracks in the street surface. About 15 percent of the annual street dirt accumulation values were washed from the street and either discharged or accumulated in the sewerage systems. About ten percent of these values were lost to the air with much of the material lost to the air settling out near the roadway. The remaining 75 percent of the annual street dirt accumulations would build up over time on the street surface or be removed by street cleaning operations.

5. Sewerage and Catchbasin Sediment Accumulations

Sewerage system sediment loadings were periodically observed in the Surrey Downs and Lake Hills study areas during the City of Bellevue project (ref.5, Section 8). Tables 40, 41, and 42 and Figure 15 summarize these observations. The sediment volumes in inlets and catchbasins were observed nine times during the two years. The storm drainage system was cleaned before the start of the project. The first observations in December, 1979 showed light accumulations.

Table 39

Approximate Annual Street Dirt Accumulation and Washoff (kg/ha/yr).

Constituent	Surrey Downs			Lake Hills		
	accumulation(1)	wash-off(2)	lost to air (3)	accumulation(1)	wash-off(2)	lost to air (3)
Total solids	200	30	20	350	60	20
COD	25	3	2	70	10	3
Total Kjeldahl N	0.2	0.04	0.02	0.8	0.16	0.05
Total P	0.1	0.02	0.01	0.2	0.05	0.01
Lead	0.1	0.02	0.01	0.4	0.1	0.02
Zinc	0.03	0.006	0.003	0.08	0.02	0.005

(1) Using an average two to five day accumulation period.
(2) See table 9-4, ref. 5.
(3) Calculated based on the deposition minus the accumulation rate times the average interevent period, by month.

Source: Pitt (ref. 5, Table 11-3).

Table 40

Stormsewer Inlet Structure Sediment Volumes and Accumulation Rates.

	# of structures:		sediment accumulation rate (1/month)		approx. months to stable volume	stable volume (1)	
Surrey Downs (38.0 ha)	total	per ha	per ha	per unit		per ha	per unit
Catchbasins	43	1.1	5.3	4.8	13	68	62
Inlets	27	0.7	2.0	2.8	20	40	57
Manholes	6	0.2	0.8	4.0	19	15	76
Average	76 (total)	2.0 (total)	8.1	4.2	15	123	62
Lake Hills (40.7 ha)							
Catchbasins	71	1.7	2.4	1.4	18	43	25
Inlets	45	1.1	1.5	1.4	14	22	20
Manholes	15	0.4	1.6	4.0	23	36	90
Average	131 (total)	3.2 (total)	5.5	1.7	18	100	31

Source: Pitt (ref. 5, Table 8-7).

Table 41

Catchbasin Sediment Chemical Quality

Particle Size (microns):	Average Concentrations (mg constituent/kg total solids)				
	COD	Total Kjeldahl nitrogen	Total phosphorous	Lead	Zinc
< 63	160,000	2,900	880	1,200	400
63→125	130,000	2,100	690	870	320
125→250	92,000	1,500	630	620	200
250→500	100,000	1,600	610	560	200
500→1000	140,000	1,600	550	540	200
1000→2000	250,000	2,600	930	540	230
2000→6350	270,000	2,500	1,100	480	190
>6350	240,000	2,100	760	290	150

Note: Surrey Downs samples collected from 1/13 to 6/17/81.

Source: Pitt (ref. 5, Table 8-4).

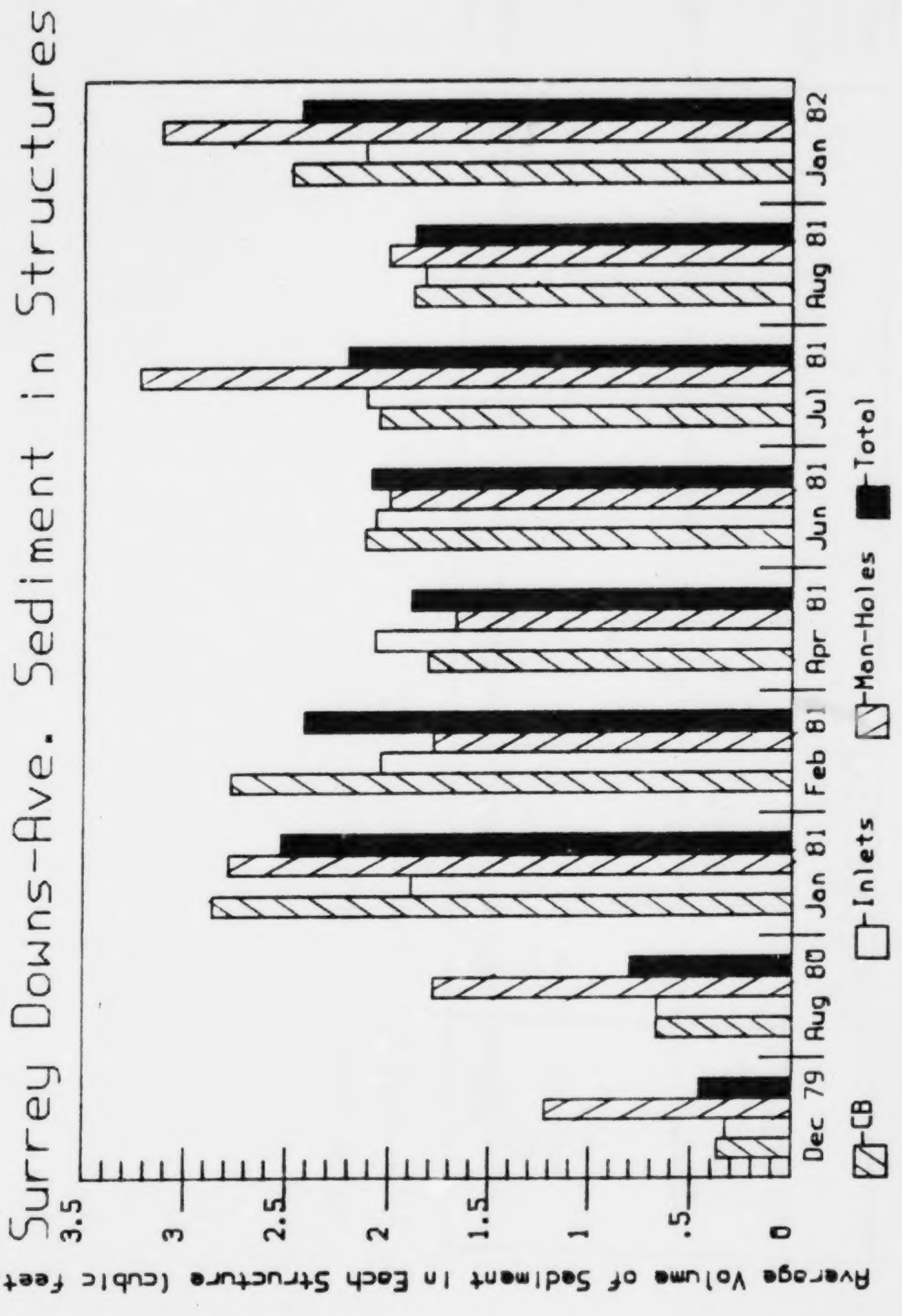
Table 42 Annual Accumulations of Sediments in Storm Sewer Inlet Structures.

	Total Solids		COD	TKN	TP	Lead	Zinc	approx.
	l/ha/yr	kg/ha/yr[1]	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/hr	kg/ha/yr	percent of total
Surrey Downs								
Catchbasins	65	100	25	0.12	0.17	0.33	0.07	67%
Inlets	24	36	9	0.04	0.06	0.12	0.02	25
Man-holes	7	11	3	0.01	0.02	0.04	0.01	8
Total	96	147	37	0.17	0.25	0.49	0.10	100%
Lake Hills								
Catchbasins	30	45	3.3	0.03	0.03	0.03	0.01	46%
Inlets	19	28	2.1	0.02	0.02	0.02	0.006	28
Man-holes	17	27	2.0	0.02	0.02	0.02	0.006	26
Total	66	100	7.5	0.07	0.07	0.07	0.02	100%

(1) assuming $1.5 g/cm^3$ wet sediment density.

Source: Pitt (ref.5, Table 8-8).

FIGURE 15



Source: Pitt (ref. 5, figure 8-1).

The next observations were made in August, 1980, and then starting in January of 1981, observations were made about every one or two months through the end of the project in January of 1982. Figure 15 shows the accumulation of particulates during the first year from December, 1979 through January, 1981.

During the second year of observations, the loadings remained about the same. Typically, there was about twice as much polluted sediments in the storm drainage systems at any one time as there were on the streets. The flushing of the sewerage sediments out of the drainage systems and into the receiving waters was not analysed but would probably not occur except for large storms. The smaller storms probably removed a small fraction of the sewerage sediments.

Table 40 shows the calculated sewerage accumulation rates in inlets and catchbasins in Surrey Downs and Lake Hills. These accumulation values were the rates observed after the initial cleaning and before the stable year two volumes were obtained. A sediment accumulation rate greater than shown in this table may be expected because of the unmonitored effects of flushing by rains that may have occurred during this time. The stable volume and the approximate period of time before the stable volume was obtained is also shown on Table 40. After the stable volumes were obtained, the urban runoff was probably little affected by this material. The constant stable volumes experienced very little washout and reaccumulation during the second year. During October of 1981 a very large storm occurred (about 100 mm of rain). However, the loading observations between August, 1981 and January, 1982 were not significantly different.

The stable sediment volumes that occurred during the second year were about 60 percent of the available sump volumes of the catchbasins and inlets. Only about 12 mm of sediment was found in the manholes with outlets on the structure bottoms, while about 150 mm of sediment were in the inlets and catchbasin sumps. When analyses were conducted for individual structures, wide variations were observed. The depth below the outlet appeared to be the most important factor but the larger capacity sumps did not always contain the largest amount of sediment. Larger sediment volumes would allow less frequent cleaning before the stable volume was obtained while smaller outlet to sump bottom distances would be associated with greater scour during storms.

The chemical quality of the sediment material in the catchbasins were also analysed. Table 41 summarizes this data by particle size. The chemical quality of this catchbasin and inlet sump material was very similar to the particle size breakdowns for the street dirt materials. Therefore, it is expected that most of the catchbasin sediments are street surface particulates that have washed off the street during rain events but were not discharged to the outfall.

Long term accumulations of the different pollutants in the different types of inlet structures are shown on Table 42. About 100 liters/hectare/year accumulated in the Surrey Downs areas while only about two-thirds of this amount accumulated in Lake Hills. There were about 50 percent more inlet structures per hectare in Lake Hills than in Surrey Downs and the accumulation rate per inlet structure was less than half in Lake Hills when compared with Surrey Downs. Nine of the ten most heavily loaded catchbasins in the first summer inventory for Surrey Downs were located on, or just upstream from, the two streets in the study area that did not have curbs. Both of these streets (108th Street and Westwood Homes Road) had extensive off-street sediment sources located along them and were not cleaned during the period of study. These nine catchbasins accounted for about 58 percent of the sediment observed in Surrey Downs during the summer inventory (a total of about one cubic meter). They also accounted for about 70 percent of the observed increases in sediment loadings observed between the first winter and the summer inventories.

A survey of the pipe dimensions and slopes throughout each of the study areas was made during the early months of the project by the City of Bellevue (ref.5, pp.8-18 through 21). Frequent observations of sediment accumulations in the pipes throughout the two study areas were also made. Very few pipes in either Surrey Downs or Lake Hills had slopes less than one percent, the slope assumed to be critical for sediment accumulation. In Lake Hills the average slope of the 118 pipes surveyed was about four percent. Only about seven percent of the pipes surveyed had slopes less than one percent in Lake Hills. In Surrey Downs the average slope of the 75 pipes surveyed was about five percent, and about 12 percent of the surveyed pipes had slopes less than one percent. Therefore, each of the study areas was drained by steeply sloping pipe systems and the accumulation of sediments in the storm drainage systems was not expected to be great.

A special sediment accumulation survey was conducted in October, 1980 to observe the magnitude and characteristics of sewerage sediments. Generally, very little sediments were found in the sewerage in Lake Hills and Surrey Downs. The pipes that had significant quantities of sediment were either sloped less than one and one-half percent, located close to a source of sediment, or were both mildly sloped and located close to a sediment source. The characteristics of the sewerage sediment were also similar to the characteristics of the sediment in the close-by manholes and catchbasins and the street surface materials. The volume of sediment accumulated in the Lake Hills pipes was about one and one-half cubic meters, or 0.04 cubic meters/hectare. Assuming a specific gravity of two grams per cubic centimeter, the sediment in Lake Hills totaled about 2800 kilograms, or 70 kilograms/hectare. In Surrey Downs, the pipe sediment volume was estimated to be more than 20 cubic meters, or one-half cubic meter/hectare or 40,000 kilograms total and 1000 kilograms/hectare. Most of the sediment in Surrey Downs was located in silted-up pipes along 108th Street and Westwood Homes Road which were not swept and had close-by major sediment sources. The pipe sediment volume estimated to be available for runoff transport in Surrey Downs was about one-third of a cubic meter or 0.01 cubic meter per hectare or about 600 kilograms or 15 kilograms/hectare.

C. URBAN RUNOFF CONTROLS

The last phase in developing an urban runoff control program is to examine the different measures that can be used to control the identified problem pollutants or flows in the different source areas or in the receiving water itself. The control measures that are appropriate for this source, accumulation area, or outfall must be identified. As examples, street cleaning can only operate on streets or parking lots (and possibly sidewalks and driveways), and construction erosion control only affects construction areas. Sewerage inlet cleaning and runoff storage and subsequent treatment can affect all source and accumulation areas, however. Development controls that reduce peak urban runoff flows need also to be systematically examined to determine the most appropriate locations in the drainage, depending on the routing of stormwater flows in the drainage system. The effectiveness of the applicable control measures in reducing problem pollutant concentrations flows and yields at the outfall and in the receiving water must be evaluated. When pollutants are removed in the watershed (such as by erosion control or by street cleaning) much more needs to be removed than the amount necessary to meet the discharge goal at the outfall. As an example, about ten kilograms of a pollutant may be needed to be removed by street cleaning to prevent one kilogram of the pollutant from entering the receiving water. This is due to the previously described inability of the rain to efficiently wash off street surface particulates and transport them to receiving waters. After the control measures' applicability and effectiveness values are known, the urban runoff control program can be designed.

In order to meet water quality objectives, a combination of several different control measures may be necessary. Complex decision analysis procedures may also be necessary if multiple objectives are important. This section describes the results of special studies to evaluate street cleaning, sewerage inlet cleaning, and detention basins in controlling the urban runoff problems in Bellevue.

1. The Effects of Street Cleaning in Controlling Urban Runoff Pollutant Discharges

The design of an effective street cleaning program requires not only a determination of the accumulation rates which were presented earlier, but also an assessment of the specific street cleaning equipment performance for the actual conditions encountered. Service goals which include effects on water quality, air quality, public safety, esthetics, and public relations must also be considered and are the driving forces in establishing a street cleaning program. The major objective addressed in this study was to determine the effectiveness of street cleaning equipment in reducing street particulate loadings and urban runoff yields.

Street cleaning performance depends on many conditions, including the character of the street surface (texture, condition, and type), street dirt characteristics (loadings and particle sizes), and other environmental factors. Street cleaning variables that most affect cleaning performance include cleaning frequency and equipment adjustment. The street cleaning tests conducted by the City of Bellevue (ref. 5, Section 10) utilized two different street cleaning frequencies. These two frequencies included no cleaning and intensive three day a week cleaning. Each cleaning frequency was employed in both the Surrey Downs main basin and the Lake Hills basins for a several month period of time and were then rotated. There was also a several month period of time when no street cleaning was conducted in either basin.

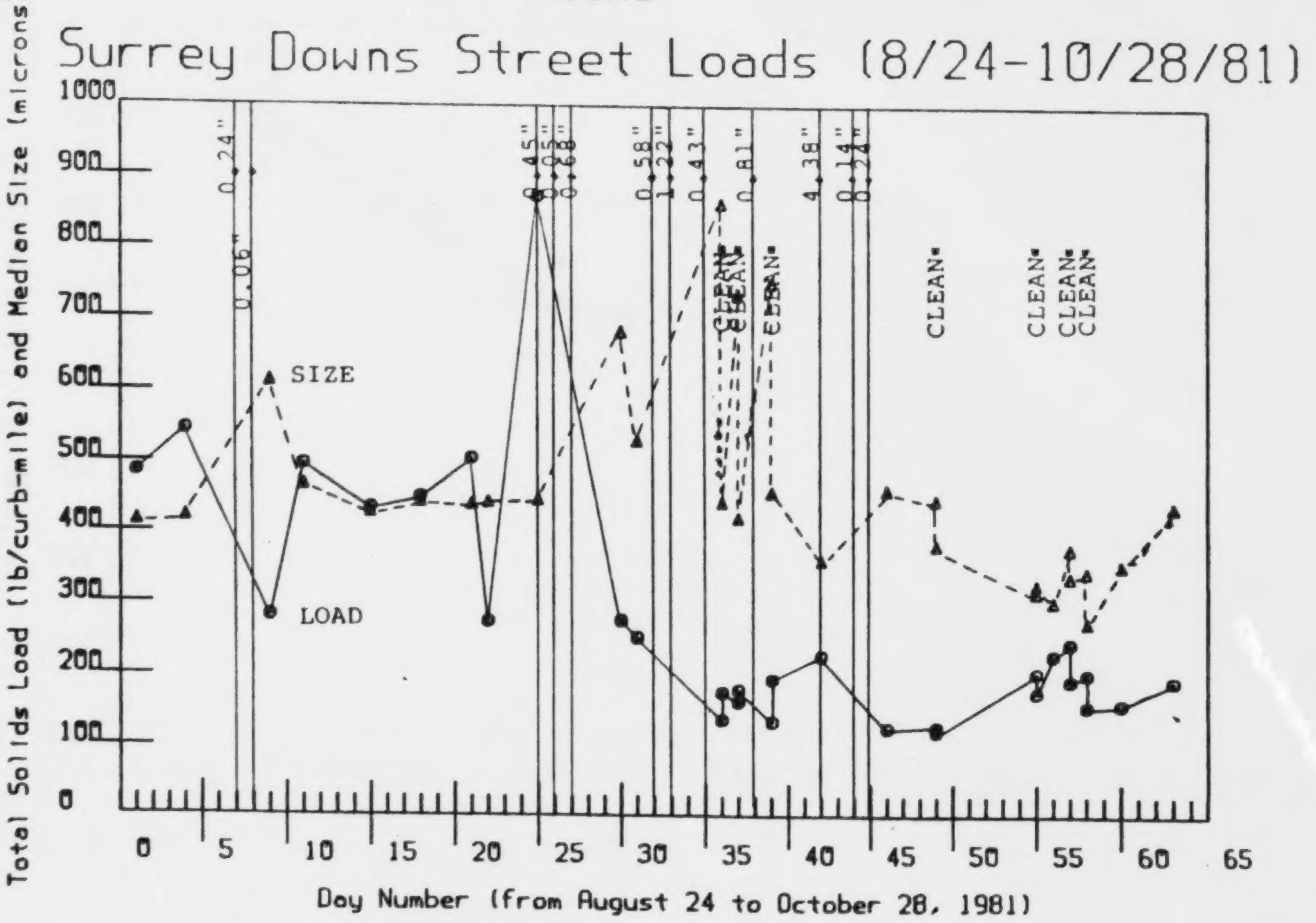
Figure 16 (ref.5, Figure 10-1) is an example of how the street cleaning operations affected the street loadings in the Surrey Downs basin. During the entire project period, street dirt loadings were about 115 grams/curb-meter (with an extreme value of about 350) during the period of no street cleaning. The loadings were reduced to about 60 grams/curb-meter shortly after the start of street cleaning. Median particle sizes decreased with the start of street cleaning because of the selective removal of the large particle sizes by street cleaners. The significant effects that rains had on the street dirt loadings and particle sizes is also shown on this figure. The rain periods shown all reduced the street surface loadings appreciably, except for the largest rain observed during the study which occurred during this period. The rains also increased the median particle sizes because they were most effective in removing the finer material. The largest rain had little effect on the net loading change, probably because of substantial erosion material carried onto the street during this major storm and the relative cleanliness of the street surface before the storm occurred.

This figure shows that street loadings responded rapidly to street cleaning. There was little lag between changes in the street cleaning program. Changes from periods of street cleaning to no street cleaning were not as rapid. The street accumulation rates were previously shown to be mostly controlled by frequent rains during periods of no street cleaning. The loading values were therefore expected to be stabilized after about three street cleanings or rains.

The Bellevue study collected many street surface particulate samples in the two test basins immediately before and immediately after the streets were cleaned. Figures 17 and 18 summarize available data for total solids and for median particle sizes. These plots show the initial street surface loads and the resultant residual street surface loads for a wide range of street surface loading conditions. Also shown on these figures is the line of no change. The different test areas where the street cleaning equipment types tested are noted on these figures. It is seen that street cleaning equipment cannot remove particulates from the street surface unless the loadings are greater than a certain amount. This value was about 85 grams/curb-meter in the test basins for the mechanical broom street cleaners and about 30 grams/curb-meter for the regenerative air street cleaner. If the initial street surface loading values were smaller than this value, then the residual loadings typically were equal to the initial loadings.

There was quite a bit of scatter associated with this data. Some of the scatter was associated with the sampling procedures which were designed to obtain loading values with an error value of about 25 percent. Other variations in observed loadings are due to street cleaning equipment operating on relatively clean streets where they loosen rather than remove some of the street surface material. Therefore, the street surface particulate loadings after the streets are cleaned may actually be greater than the loadings before. Statistical analysis showed that the frequent rains in Bellevue were probably more effective than the street cleaning in keeping the Bellevue streets clean. The street surface loadings after rains were usually about 50 grams/curb-meter

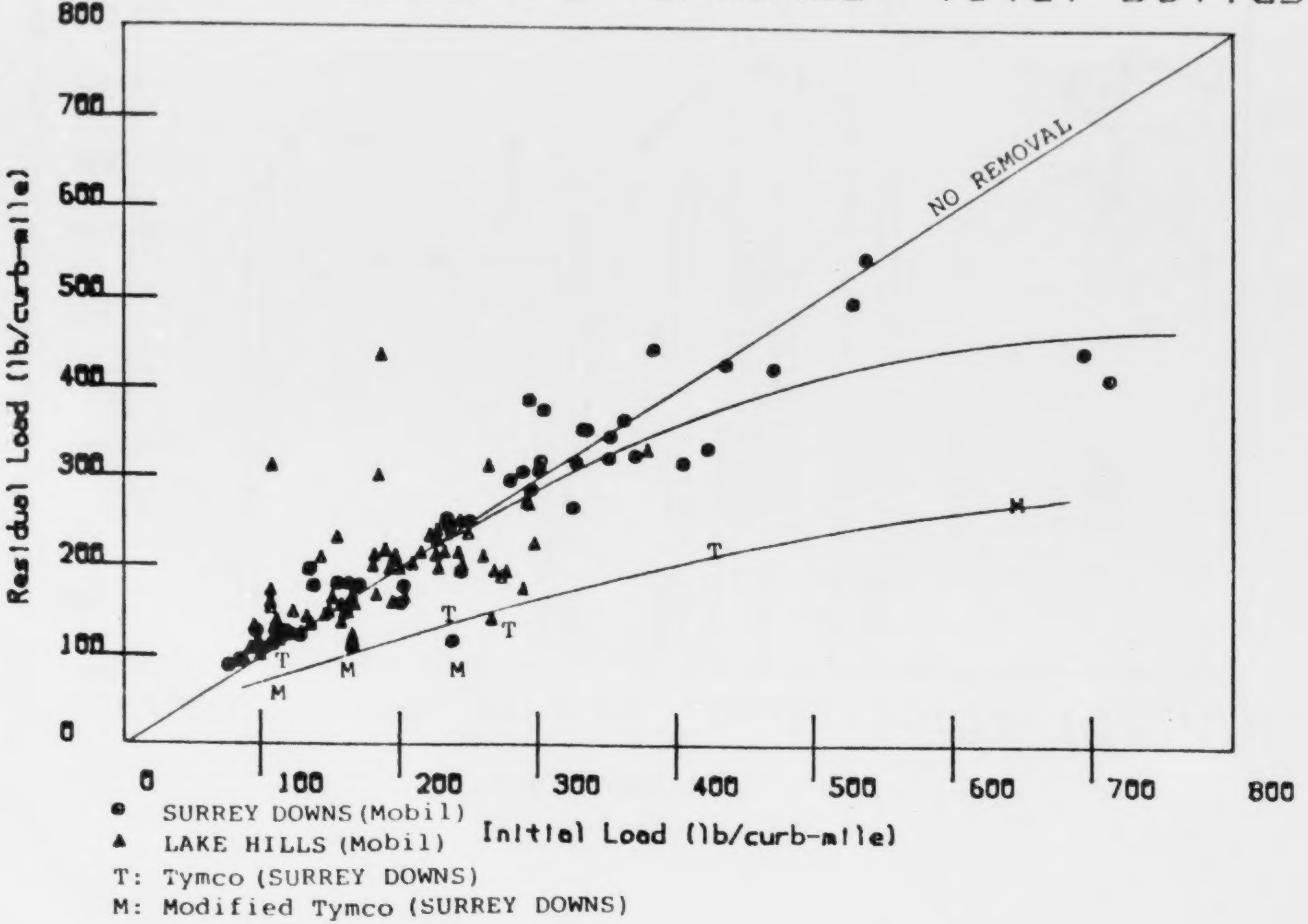
FIGURE 16



Source: Pitt (ref. 5, figure 10-1).

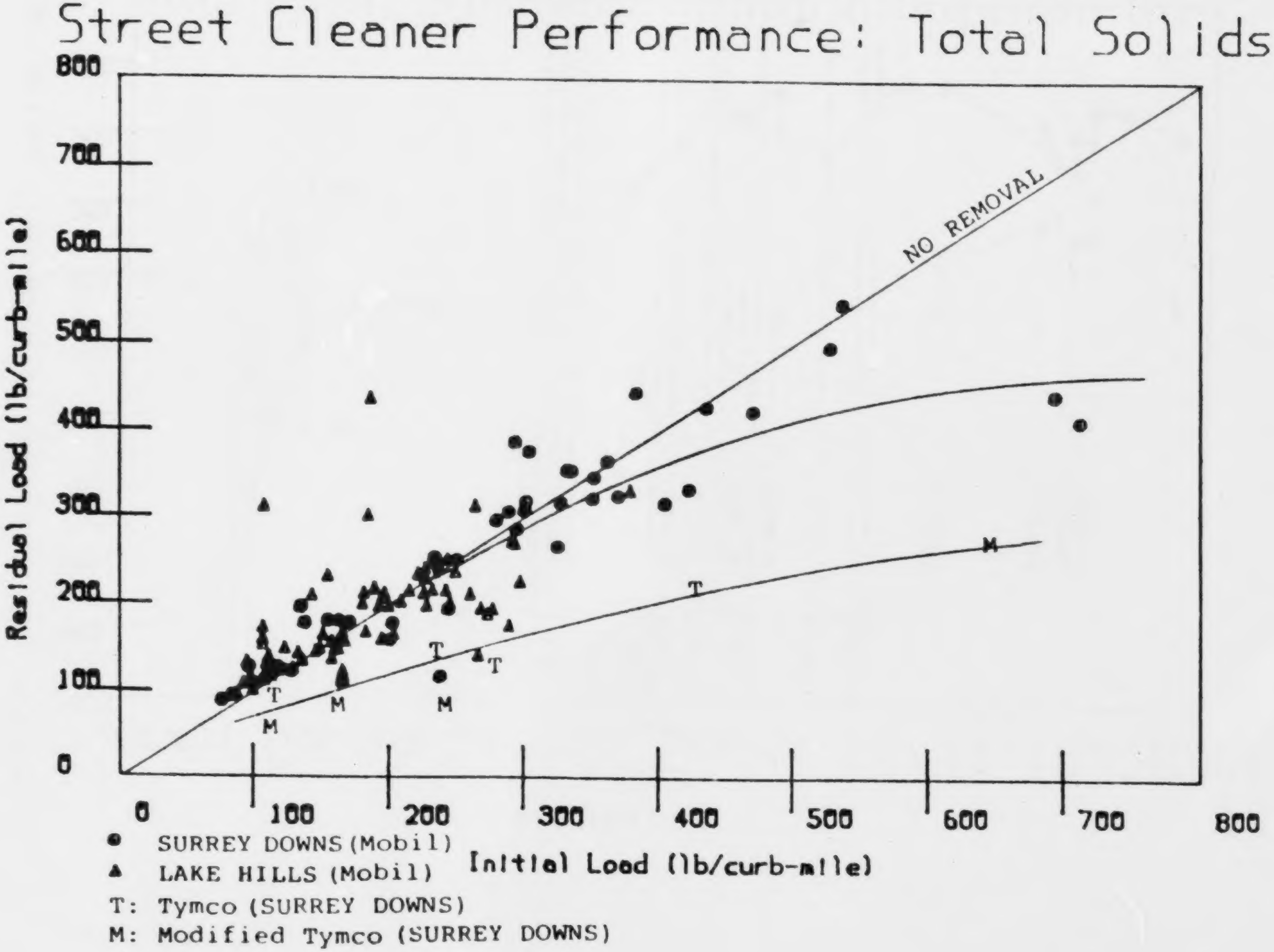
FIGURE 17

Street Cleaner Performance: Total Solids



Source: Pitt (ref. 5, figure 10-2).

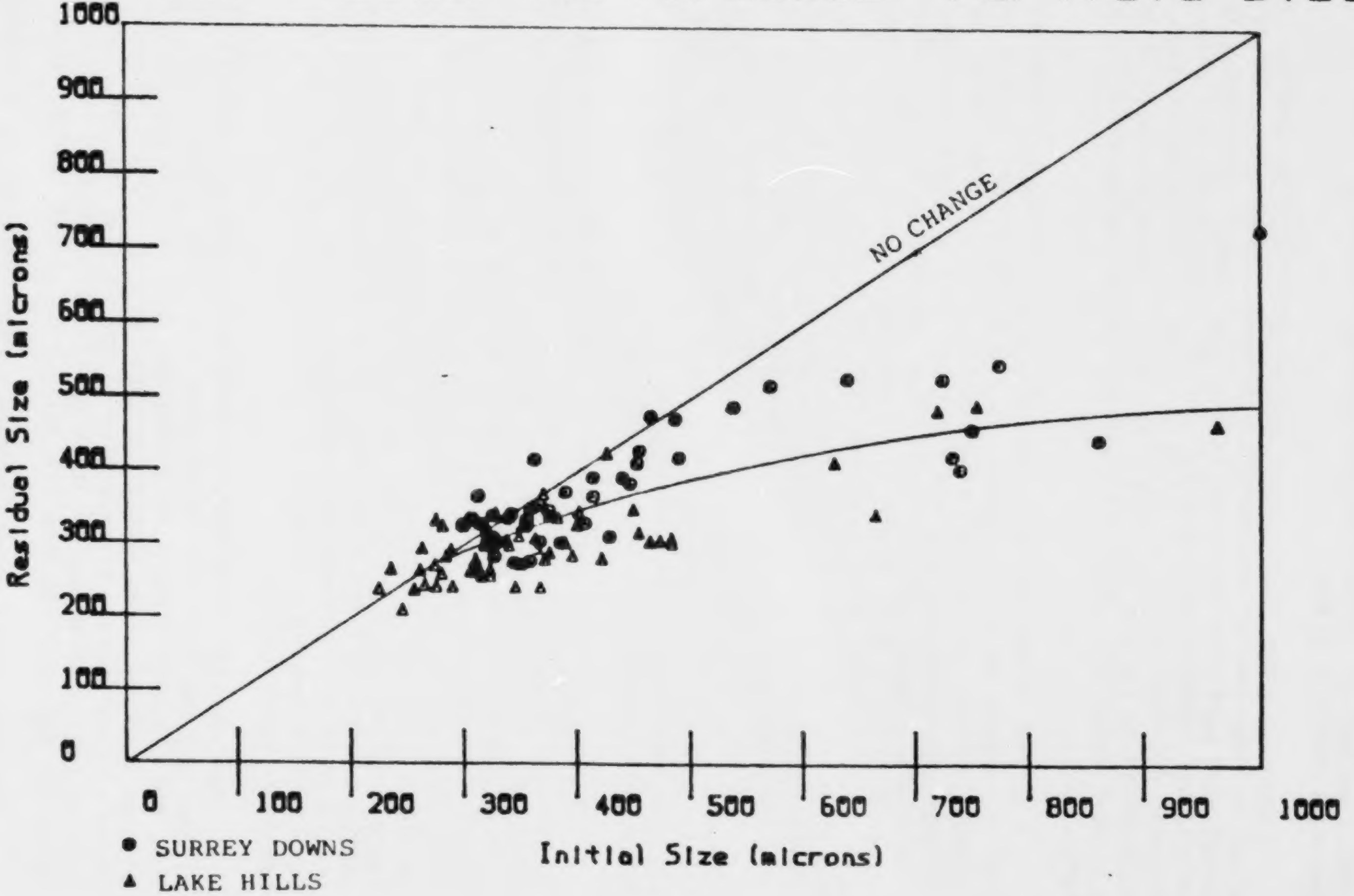
FIGURE 17



Source: Pitt (ref. 5, figure 10-2).

FIGURE 18

Street Cleaner Performance: Particle Size



Source: Pitt (ref. 5, figure 10-3).

and the mechanical street cleaning equipment could only remove the street surface particulates down to about 85 grams/curb-meter. It was also found that typical mechanical street cleaning equipment is quite ineffective in removing the small particle sizes.

Figure 18 shows that initial median particle sizes smaller than about 300 or 400 microns are not substantially altered. There was no effective removal of street dirt particles that were smaller than about 125 microns. However, very substantial removals were observed for the large particles. Figure 18 shows the dramatic decrease in median particle sizes as the street cleaners preferentially removed the larger particles. These decreases in median particle size were especially important when the initial median particle sizes were large.

A series of special tests were conducted during September and October of 1982 to compare the effectiveness of a modified street cleaner to standard street cleaners. Air Pollution Technology, Inc., of San Diego, California, designed and installed many modifications to a standard regenerative air street cleaner while under contract to EPA (William Kuykendal, project officer, Research Triangle Park, North Carolina). The purpose of these modifications were to reduce respirable fugitive dust emissions during street cleaning. The modifications included partial hoods around the gutter brooms, a pressure controller to better regulate the air flows, and a venturi scrubber with a settling chamber in the street cleaner hopper. The water spray bar was also disconnected. This modified street cleaner was compared to both a standard street cleaner that was used in the previous full scale Bellevue tests and to itself with the modifications disconnected. The results of these special tests are also shown on Figure 17 marked by the letters "T" and "M" for the standard Tymco regenerative air street cleaner and the modified Tymco street cleaner.

The regenerative air street cleaner modified and not modified showed substantially better performance than the regular mechanical street cleaner during the special tests. This was especially true considering the better performance associated with the finer particle sizes. The mechanical broom street cleaner removed very little of the particles less than 1000 microns in size. This poor performance was aggravated by the low loadings of the small particles. The regenerative air cleaners appeared much more suited for these lower loadings, especially for the smaller particle sizes. The data for the smallest particle sizes (less than 125 microns) was inconsistent, implying little consistent removal effectiveness by any of the street cleaners. Similar results were obtained for both the Surrey Downs area and for the S.E. 30th Street industrial site.

Much greater differences between the standard regenerative air street cleaner and the modified regenerative air street cleaner were obtained when only the cleaning width street loadings were considered. The modified street cleaner resulted in an almost constant residual loading value in the cleaning width after cleaning, irrespective of the initial loading. This indicates a very important advantage in the cleaning effectiveness for the street cleaner which was not apparent when the full width street loading data were reviewed.

The loadings of street surface particulates in the parking lanes (cleaning width) were also monitored during the two-year period of study in both Lake Hills and Surrey Downs. Only street surface loadings present in the parking lanes are available for removal by street cleaning. In all cases, about 55 to

65 percent of the total street surface loadings were found in these curb-side parking lanes, In Lake Hills, about 15 to 30 grams/curb-meter total solids were found in the curb-side lanes, while about 60 to 85 grams/curb-meter were found in the curb-side lanes in Surrey Downs during periods of no street cleaning. The observed differences in loadings in the driving lanes were much less. Driving lane loadings in Lake Hills ranged from about 15 to 20 grams/curb-meter wile they were about 35 to 40 grams/curb-meter in Surrey Downs during periods of no street cleaning. The driving lane loadings were probably increased when the parking lane loadings were high because of winds transporting particulates out into the street. Almost all of the largest particles (greater than 6350 microns) were found in the parking lanes in both test areas.

Tests were also conducted to determine the redistribution of street surface material across the street during street cleaning operations. The unit area loadings in the 25 centimeters next to the curb were reduced substantially in these tests. The other street segments experienced variable loading changes indicating substantial movement of the near-curb dust and dirt away from the curb by the street cleaning gutter brooms. The main pickup brooms were not able to remove all of this moved material possibly because of ineffective deflection plates.

The costs of street cleaning by the City of Bellevue are summarized in Table 43 for the two-year project period. The total street cleaning costs were about $13/curb-kilometer, which is quite similar to costs at other locations. About 73 percent of this cost is associated with labor and labor overhead, while about 18 percent is associated with all of the maintenance costs, and another 18 percent with the disposal costs. The street cleaner operating costs, including labor, depreciation, tires, oil, and gasoline, were about 64 percent of these total costs. Therefore, street cleaning operations can be considered a labor intensive activity.

The City of Bellevue has two street cleaners. They are both four wheel mechanical broom cleaners with dual gasoline engines. Operating on a part time basis, they clean about 24 to 30 kilometers each day while operating at about 11 km/hr. These cleaning speeds were much less effective than the usually recommended 6.5 km/hr. These speed differences are especially important for heavier loadings (greater than about 400 grams/curb-meter). The current Bellevue street cleaning program productivity may therefore be improved by reducing the vehicle speeds but at an increase in cost if the cleaning frequency remains the same. Reducing the speeds may be especially important on dirtier industrial streets.

A large amount of data analysis effort during the Bellevue City project was directed towards attempting to identify differences in runoff concentrations and yields caused by street cleaning operations (ref. 5, Section 9). No significant differences in runoff yields or concentrations during periods of intensive street cleaning versus no street cleaning were observed. Very few exceptions were observed but were probably due to other factors.

The reason for this poor effectiveness of street cleaning is probably because of the specific Bellevue rainfall conditions. As noted earlier, the rainfall and resultant runoff volumes varied by large amounts (by at least 25 percent for about half of the rain pairs) between the two test areas. These different rain and runoff volume differences could result in shielding any effects caused by the street cleaning operations. Earlier it was shown that the contributions of street surface particulates to runoff yields was less than 25

Table 43 Bellevue Street Cleaning Costs (1980-1982)

Item	Typical Cost per year	Percentage of total costs	Unit Costs ($/curb-km cleaned)
Labor:			
Repair labor	$ 10,780	8.3%	$ 1.05
Disposal labor	9,130	7.0	0.89
Operator labor	61,280	46.8	5.93
Labor overhead	14,210	10.9	1.38
Equipment Operation Maintenance, Debris Disposal, Etc.:			
Street cleaner depreciation	$ 5,300	4.1	0.52
Disposal equipment depreciation	12,400	9.5	1.21
Outside services	675	0.5	0.06
Repair parts (includes brooms)	10,240	7.8	0.99
Tires	710	0.5	0.06
Oil	120	0.1	0.01
Gasoline	5,890	4.5	0.57
Total	$130,735	100 %	$12.57 per curb-km.

percent in almost all cases. Street surfaces, however, contributed about fifty percent of the total runoff lead yield.

If the street cleaning operations could control a substantial fraction of the street surface particulates that could be washed off the street, then runoff lead improvements may have been observed. It was also shown, however, that rains were most effective in removing particles smaller than several hundred microns in size. These particle sizes contain the largest concentrations of the heavy metals and relatively large concentrations of many of the nutrients and other constituents of concern. Normal street cleaning equipment, however, is not very effective in removing the small particle sizes and can only effectively remove the particle sizes greater than several hundred microns. The special modified regenerative air street cleaners, however, were quite effective in removing the smaller particle sizes.

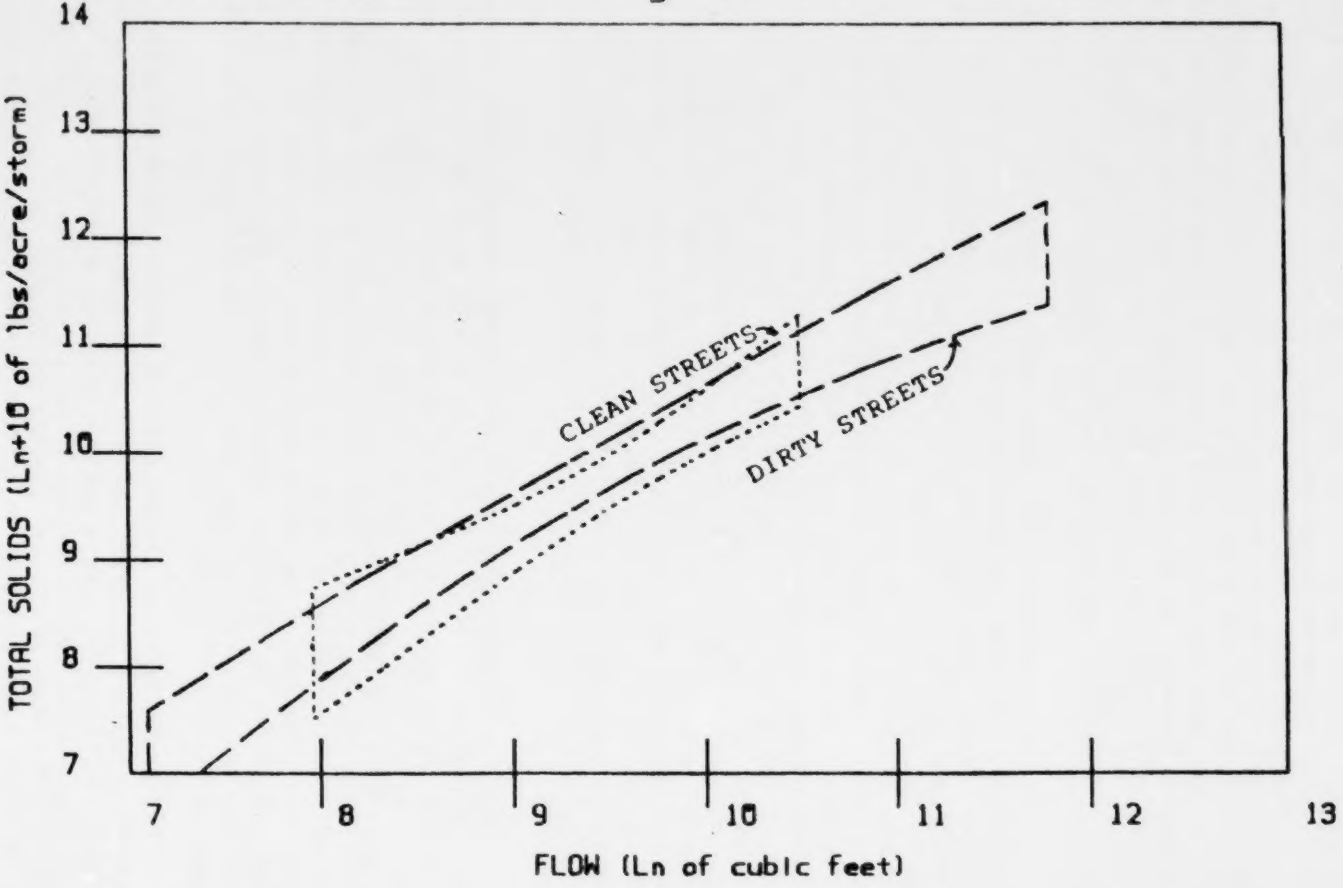
The coordination of the street surface sampling, street cleaning operations, and runoff monitoring activities during the City of Bellevue project allowed many different data analysis procedures to be used to investigate possible effects of street cleaning on runoff water quality. The use of two test basins and the rotation of the street cleaning operations also allowed one basin to be compared against the other basin along with internal basin comparisons. Figure 19 is an example of the observed total solids concentrations in a single basin during a single season. Figure 20 is an example of the analyses comparing one basin to the other basin and the calibration period of no street cleaning. These plots were developed using regression analyses that were performed on log-transformed concentration and flow data for periods of different street cleaning operations and seasons of the year. Ninety-five percent confidence intervals for these sets of data are shown. There were no significant differences noted in the concentrations over the ranges of data that were common to the different data sets. The confidence intervals overlapped over most of the concentration ranges indicating the lack of significant differences (at the 95 percent level of significance or greater).

There were many cases where the lowest concentrations of runoff water quality were associated with periods of time when the streets were not being cleaned. Increased concentrations during periods of increased street cleaning may be associated with a loss of large armoring particles. Bed armoring can occur when large stable particles rest upon and pin smaller unstable particles that would otherwise be lifted and transported by rain washoff. Since the street cleaner removes or disturbs a significant portion of the larger particles, the runoff may be more efficient in removing the smaller particles that remain during intensive street cleaning. Other activities such as wind, traffic, and local erosion may have the same effect as street cleaning by removing or disturbing the armor.

Different types of street cleaning programs were evaluated in reducing the washoff potential of street surface particulates by the Bellevue project (ref.5, Section 10). Street surface loadings averaged about 115 grams/curb-meter during periods of no street cleaning in both sites. The frequent Bellevue rains were capable of keeping the smooth asphalt streets quite clean (when compared to typical loadings elsewhere on the West Coast) for no cleaning periods. Intensive three times a week street cleaning reduced these loadings to about 60 grams/curb-meter. The most significant loading reductions during the street cleaning operations were observed for the larger particle

FIGURE 19

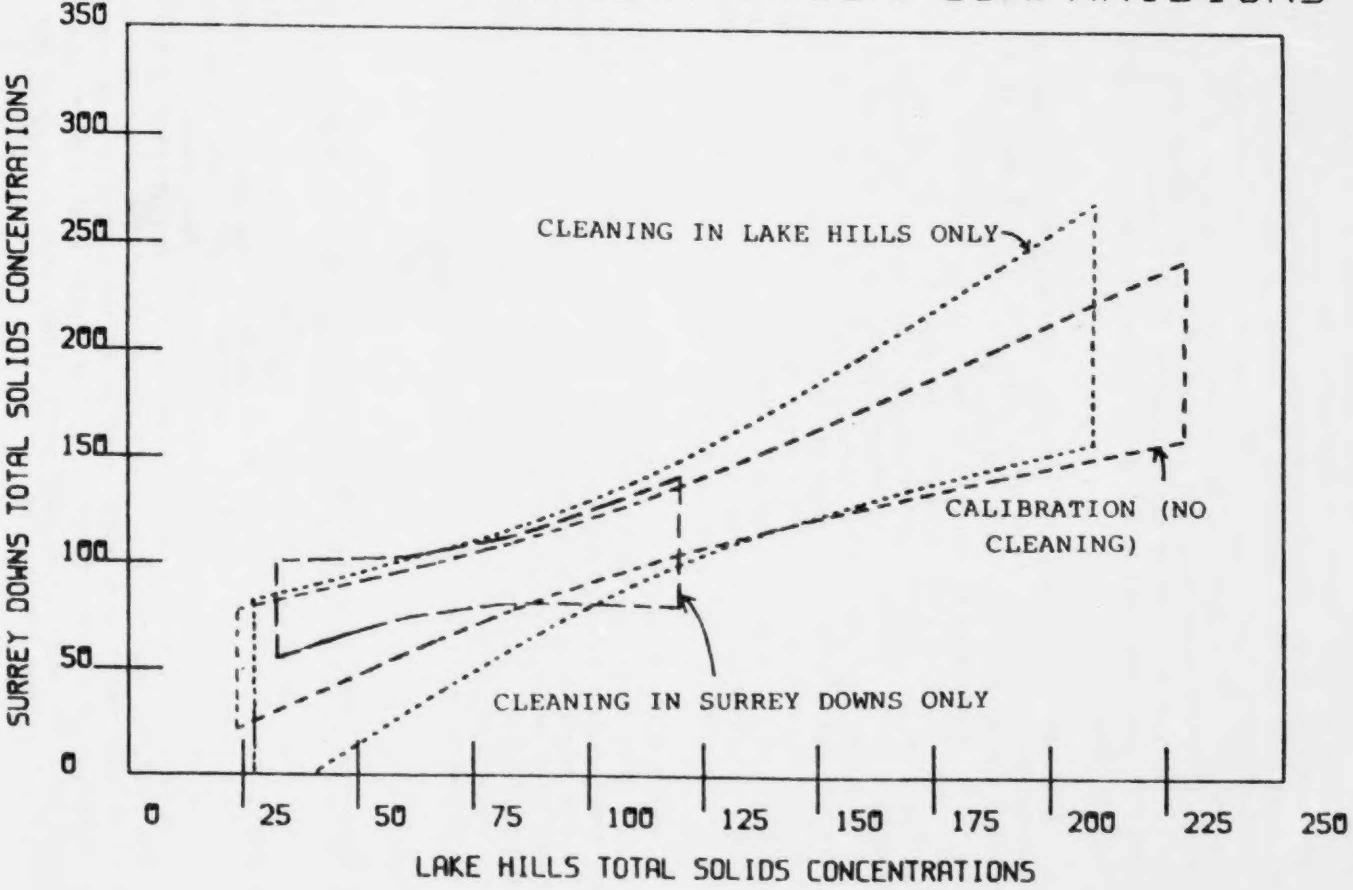
TOTAL SOLIDS - Dry Season -Lake Hills



Source: Pitt (ref. 5, figure 9-11).

FIGURE 20

TOTAL SOLIDS CONCENTRATION COMPARISIONS



Source: Pitt (ref. 5, figure 9-22).

sizes (greater than 250 microns).

Figure 21 shows how the street dirt loadings were removed for all street cleaning tests in Lake Hills and Surrey Downs with intensive street cleaning. Also shown on this figure is the reduction in washoff potential associated with each particle size. This figure shows that intensive street cleaning resulted in about a 25 percent reduction in street surface loadings when compared to no street cleaning conditions. If the street surface contributes about half of the total source for a specific pollutant, then intensive street cleaning may only remove slightly more than ten percent of the pollutant yield at the outfall. It would, therefore, require quite precise runoff measurements and very consistent rainfalls over the test and control basins in order to detect differences as small as these.

Table 44 summarizes the approximate benefits that street cleaning may have on reducing the runoff load associated with street washoff for very small and heavier rains. For very small rains, street surface washoff is estimated to contribute more than 60 percent of most of the constituents to the runoff yield. For larger rains, however, the importance of street washoff diminishes; but lead, zinc, and COD contributions from street surfaces are still quite important. With intensive street cleaning, only the larger particle sizes are significantly reduced, while those particle sizes most subjected to washoff by rains are not effectively reduced. This may result in less than a six percent expected improvement in runoff water quality for intensive street cleaning. The modified regenerative air street cleaner is only expected to have a slightly better effectiveness in reducing runoff yields. The modified street cleaner may reduce the runoff yields by as much as ten percent.

The effectiveness of street cleaning equipment in controlling urban runoff is very site specific. If the street surface loadings were much greater than the break-even street cleaning point and there were less frequent rains, street cleaning might control important fractions of the total urban runoff flows. Street cleaning operations in Bellevue may not be an appropriate urban runoff control measure. With such small potential improvements in urban runoff quality at a relatively high cost, the other street cleaning program benefits are probably more important in designing the street cleaning program.

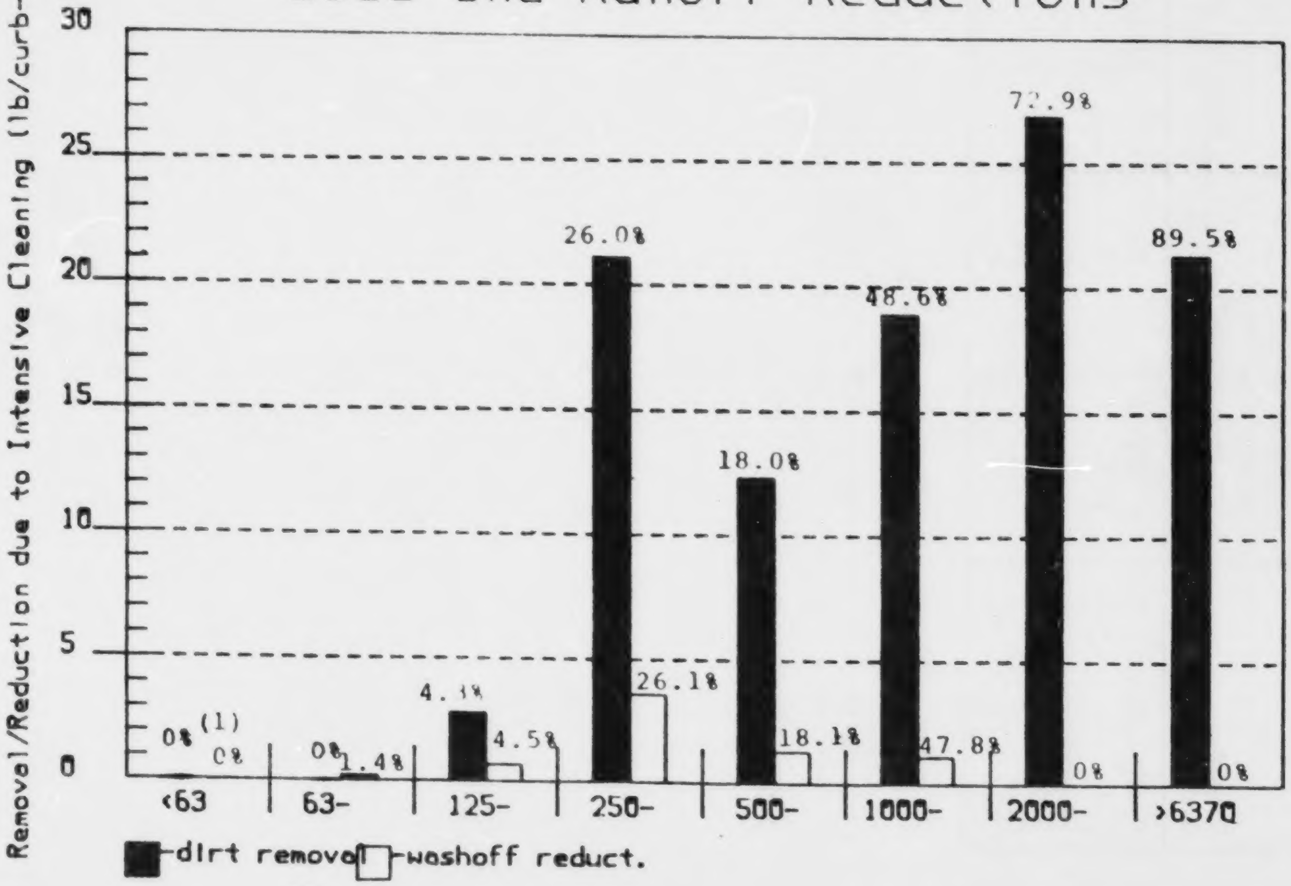
2. Sewerage Inlet Cleaning Effects in Reducing Urban Runoff Yields

The City of Bellevue's project (ref. 5, Section 11) also studied the potential benefits of cleaning sewerage inlet structures in controlling urban runoff discharges. The catchbasin sediment material was found to be made up mostly of street surface particulates that had been removed from the street surface during rains and accumulated in the sumps instead of being discharged at the outfall. The chemical characteristics of the catchbasin material on a particle size basis were quite similar to the particle size chemical characteristics of the street dirt. The particle size distribution, however, showed that the catchbasin sump particulates were made up of many more fine particles than the street dirt.

The rains preferentially removed the finer more heavily polluted and more available materials during washoff. The sediments in the catchbasins and the sewerage were mostly the largest particles that were washed off the street.

FIGURE 21

Load and Runoff Reductions



(1) Percent reduction when intensive cleaning is compared to no cleaning.

Source: Pitt (ref. 5, figure 10-14).

Table 44 Effects of Street Cleaning on Runoff Loads(1)

Runoff Pollutant	Approximate Percent of total runoff load from street washoff		Percent Runoff Load Reduction for Intensive street cleaning	
	0.25 mm rain	≥2.5 mm rain	0.25 mm rain	≥2.5 mm rain
Total Solids	65%	10%	6.4%	1%
COD	62	40	6	4
Phosphates	61	31	6	3
Total Kjeldahl N	61	31	6	3
Lead	60	60	6	6
Zinc	61	45	6	4.5

(1)The values shown are based on the 4-wheel mechanical street cleaner tests. The regenerative air street cleaners are estimated to be about 1.25 times as effective as the above values, due to their better performance on removing the more washable fine particles.

Source: Pitt (ref. 5, Table 10-4).

These sediments had a much smaller median particle size than the street surface particulates, and were therefore more potentially polluting than the particulates that can be removed by normal street cleaning operations. The catchbasin and storm sewerage sediments, however, may not contribute large quantities of pollutants to the urban runoff yield, except for very rare flushing events, even if not cleaned. If the catchbasins are full, they may have little effect on the runoff yields.

Catchbasin sump sediments can be relatively conveniently removed to eliminate this potential source of urban runoff pollutants. Because the catchbasin sediment accumulation rate is quite low, frequent cleaning of catchbasins is not necessary. It is expected that cleaning catchbasins twice a year at the most would be sufficient.

Only about 60 percent of the available sump volumes in the inlets were used for detention of particulates. Large sumps had less of their volume utilized. The structures with large sump volumes could be cleaned less frequently and hold larger volumes of sediments. It is expected that cleaning these inlet sumps about twice a year could reduce the lead and total solids urban runoff discharges by between ten and 25 percent. COD, total Kjeldahl nitrogen, total phosphorus, and zinc may be controlled by between five and ten percent with semi-annual catchbasin cleaning. Cleaning less frequently than this would reduce these expected improvements. If the catchbasin sumps are left full, the potential for dramatically increasing runoff yields during rare events exists.

Some pollutants may also be chemically changed by oxidation-reduction reactions or other chemical or biological changes in the catchbasins which could make them more soluble and therefore more available to receiving water organisms.

3. The Use of Detention Basins in Controlling Urban Runoff Discharges

The USGS (ref. 1) tested the effectiveness of a detention facility in the 148th Avenue S.E. catchment. The detention basin system consisted of five normally dry grass-lined swales which were contoured into a small park adjacent to the road. The swales were about 300 meters long and 30 meters wide. There were five control structures used to regulate the flow and the storage along the 27-inch trunk line running under the park. The original design of the detention system permitted the flow and storage to be regulated by weirs and valves. Runoff from low intensity storms was originally allowed to pass through the system with little detention, while discharges from higher intensity storms was detained behind the weirs in the 27-inch trunk line. During extreme events, the higher flows ran over the weirs when the detention basins were full.

During the study, the USGS (ref.1, p.8) modified the control structures to permit the slow release of water stored in the detention basin which was then monitored with a recorder installed behind the weir. Water was therefore stored during much smaller rains than in the original configuration. The detention time was about 30 minutes or less, which was sufficient time for settling of sand and some coarse silt. Much of the finer material, however, was probably transported directly through the detention system. Earlier data (ref. 6, Table 31) indicated that most of the suspended sediment in the storm runoff at this site was finer than 62 microns.

The results of the data (ref.6, pp.101-122) indicated that the detention of the storm runoff had little effect on the concentrations of the suspended constituents; but it slightly increased, or had little effect on the concentrations of the dissolved constituents. The geometric mean ratio of the outflow to the inflow average dissolved solids concentrations was 1.11, indicating an 11 percent increase in concentration due to detention. The significance of this increase, however, was quite small. Only suspended phosphorus had a probability greater than 75 percent that the inflow and the outflow concentrations were different. The suspended solids concentration probability was only about 50 percent.

The performance of the detention basins on the four to seven storms that were tested seemed mostly to depend on the distribution of the constituents between the suspended and dissolved phases.

The volume of the storm sewer behind the weir used to control the flow was adequate to store the runoff during about 70 percent of the storms that occurred during that phase of the study. For the other 30 percent of the storms, the volume of the sewer was insufficient to store all the detained water and some was backed up into the grass lined depressed area. When the grassy area was inspected after a storm, only a trace of fine residual material was noted on the blades of grass.

Over the entire detention phase of the study, there were about 20 storms (about ten percent of all storms) that were large enough to cause detention in the grassy swale. At the end of the study, only a small amount of suspended sediment was seen on the grass. An approximation was made to estimate the amount of sediment trapped in the detention system at the end of the study. It was estimated that less than one-tenth of the total amount transported through the system was detained. The suspended solids concentrations in the discreet samples often increased toward the end of the storms because of scouring of previously settled material from the detention system.

Seattle METRO (ref.2, pp.3-85 through 3-87) obtained a sample of the detention basin sediment for priority pollutant analyses. Table 45 summarizes these observations. Most of the elements and compounds in the detention basin sediments had similar concentrations to the local street dirt samples. The lead concentrations, however, were much greater in the detention basins than in the street dirt, while the chromium and copper concentrations were much lower. Zinc was somewhere between the detention basin sediments and the street dirt concentrations.

METRO reviewed the particle size distributions of the sediment material and the street dirt and concluded that differences in particle size distributions could not fully explain the differences in lead concentrations observed.

The USGS (ref. 6, p.70) also examined the ability of the detention facility to affect the discharge rate of storms. They found more than a 99 percent probability that the detention facility affected the peak discharge rate. The average ratio of peak discharge rates without detention to detention was 0.63. However, there was only a 51 percent probability that the detention facility affected the response time of the catchment. The response time effect

Table 45 Priority Pollutant Concentrations Found in 148th Ave. S.E. Detention Basin Sediment (single sample collected in March, 1982)

Constituents	mg constituent/ kg total solids (dry weight)
(Inorganics)	
Antimony	1.3
Arsenic	19.0
Beryllium	0.19
Cadmium	1.4
Chromium	20
Copper	35
Lead	600
Mercury	0.11
Nickel	20
Selenium	<0.6
Silver	0.08
Thallium	<0.2
Zinc	310
Cyanides	0.18
(Organics)	
Fluoranthene	2.5
Benzo(a)anthracene	1.1
Chrysene	2.0
Phenanthrene	2.1
Pyrene	3.0
Toluene	0.12
α-BHC	0.00045
β-BHC	0.00019
δ-BHC	0.00042

Source: Galvin and Moore (ref. 2, table 53).

noted was only about one minute, which is not important.

The USGS (ref.6, p.109) concluded that the effectiveness of the detention system in removing suspended material could have been improved by the periodic removal of the deposited sediment. The removal of the deposited sediment at the end of the summer would have prevented the resuspension and transport of the sediment during the fall and winter rains.

BELLEVUE SURFACE WATER QUALITY PROBLEMS

The Storm and Surface Water Utility of the City of Bellevue has actively responded to citizen complaints, requests, and comments concerning water quality problems for many years. Most of these citizen contacts are initiated when people see illegal discharges into stormdrain inlets or observe fish kills or aesthetic problems in the city creeks. They then telephone the Storm and Surface Water Utility who responds with site investigations and necessary clean-up activities. The Utility owns remedial clean-up equipment (booms and vacuum pumps) and can call upon the Bellevue Public Works Department or the Washington State Department of Ecology for assistance.

These accidental and/or illegal discharges can create receiving water effects ranging from nuisances to large fish kills. These discharges cannot be easily quantified, but their effects are probably more dramatic than the effects of "regular" stormwater discharges that are described in other sections of this report. Most of these problems are associated with urbanization and should be considered as part of the urban runoff problem, even though they are usually illegal.

The following list briefly summarizes some of the citizen contacts that occurred from June 1980 through August 1983. There were obviously other water quality problems that occurred during this time that were not reported, so these experiences should be considered as just a sample of urban water quality problems that can typically occur.

June 1980. Oil drained into catchbasin. Cleaned out catchbasin and lectured person responsible.

July 1980. Oil in catchbasin. Catchbasin cleaned.

Sept. 1980. Car wash discharging soapy water into stormdrains. Practice discontinued.

Sept. 1980. Oil drained into catchbasin. Warned car owner of possible fines and cleaned out catchbasin.

Sept. 1980. Oil in catchbasin. Catchbasin cleaned.

Sept. 1980. About 40 gallons of oil dumped in catchbasin. Cleaned catchbasin.

November 1980. Complaint of colored (reddish) creek during some storms. Sample requested next time observed.

December 1980. Oil drained in inlet. Already flushed through stormdrain, left warning note on house.

April 1981. Building contractor flushed concrete wash water into stormdrain. Contractor cleaned out stormdrain and catchbasin.

May 1981. Soap from hotel cleaning crew dumped into stormdrain. Warned hotel to stop practice.

June 1981. Unknown material dumped into stormdrain at building material yard, cleaning fluid discharged into inlets, and grease and oil from car rental agency dumped into stormdrain. Checked out mortor coloring material dumped by building material yard and periodically monitored inlets at other industries.

June 1981. Oil drained into catchbasin on the weekend. Attempted to locate described automobile responsible.

June 1981. Oil sheen and smell at mouth of Coal Creek at beginning of thunderstorm. Several sites visited without detecting oil residue. High turbidity in creek due to storm.

July 1981. Several dead fish reported in Kelsey Creek and sheen on water. Samples taken. Fish possibly died during high flows of recent storm. Sheen from flushed catchbasins.

July 1981. Paint in catchbasin. Cleaned out about two or three gallons of paint and thinner from catchbasin, with painters assistance. Painter lectured.

October 1981. Diesel base substance on street. Most of the material already flushed into stormdrain. Boomed creek. Observed tank truck near outlet, leaving area.

January 1982. White milky substance drained into Lake Washington. Referred complaint to adjacent city.

January 1982. Concrete truck rinsed out into catchbasin. Owner notified and warned.

August 1982. Concrete trucks rinsed wastes into storm drainage. Owner notified and warned by State Department of Ecology.

October 1982. Complaint of turbid outfall discharge into Lake Sammamish. Investigated but no conclusion.

October 1982. Industrial discharge of cleaning solutions into stormdrain. Informed of law violation and investigated possible hookup to sanitary sewer.

November 1982. Drainage ditch carrying white material. Found roofing material (waterbase latex coating of one percent ethylene glycol plus acrylic resins and titanium dioxide) recently applied being washed off roof during storm. Notified roofing contractor of illegal, but inadvertant, discharge.

January 1983. Yacht club complained of oily and fibrous stormdrain discharge during major storms adhering to boats. Investigated with no conclusion.

January 1983. Industrial cleaning solution still being discharged into creek. Encouraged discharge into sanitary sewer.

January 1983. Oil discharged into inlet. Investigated, but all oil was flushed into storm sewer. Provided resident with list of waste oil recyclers. referred complainer who wished to pursue matter to Dept. of Ecology.

February 1983. Prior employee complained about paint stripper (chlorinated solvent) and laquer thinner discharge into floor drain at furniture refinisher. Investigated and referred to METRO Industrial Waste for further action.

February 1983. Complaint of gas smell along Lake Sammamish. Investigated, but no smell apparent.

March 1983. High turbidity in Richards Creek. Investigated and found high turbidity and petroleum odor in creek. Found a lot cleaning operation in progress. Filter fabrics were installed below grates and catchbasins were cleaned.

March 1983. Eductor cleaning contractor cleaned storm system, but dumped waste on vacant lot. The material flowed off the lot and back into the stormdrain system. Contractor informed of problem and catchbasins were cleaned again.

March 1983. Dead Robins in creek. Investigated and found that the birds were probably killed by flying into glassed walkway that crosses creek. Suggested the use of decals to make the glass more visible.

March 1983. Septic tank smell in stormdrain. Found pipe entering catchbasin discharging septic tank drainage wastes. City Environmental Health division followed up. Septic tank drain field rebuilt and disconnected from storm sewer.

March 1983. Red color in Sears Creek. Found dumpster leaking red paint that was hosed into stormdrain. Enforcement action by Dept. of Ecology. Recommended that paint not be placed in trash compactor.

April 1983. High stream turbidity in Sturtevant Creek. Source found to be street dirt at construction site being flushed into stormdrains during street cleaning.

April 1983. Continued complaints of soap in Kelsey Creek, mostly on weekends. Thought to be same cleaning firm discharging wastes into stormdrains. Not enough evidence for enforcement action.

May 1983. Plastering tools being cleaned and wash water discharged into stormdrains. Residue removed.

May 1983. Used cooking oil from restaurant dumped into stormdrain daily. Referred to Dept. of Ecology for action (outside city).

May 1983. High stream turbidity. Possible source was old fish packing ice melt water running into stormdrain. Sanitary floor drain will be used in the future.

May 1983. Auto repair shop dumping oil into catchbasin. Did not find any evidence of oil in catchbasin. Suggested minor housekeeping improvements.

May 1983. Turbidity in small creek. Possible upstream construction source.

May 1983. Oily scum and debris near outfall at Lake Bellevue. Unknown source. Scum possible from creosote leachate from piles. Debris from low flows and winds.

May 1983. White powdery residue near stormdrains thought to be from nearby swimming pool. Powder was diatomaceous earth from the pool filter. The backwash was connected to stormdrains, but connection to sanitary sewer was investigated to reduce overflow problem.

June 1983. Five gallon diesel fuel spill on street. Spread sand and swept with street cleaner to remove most of diesel. OilSweep applied to adsorb remainder.

June 1983. Oil discharged into catchbasin. Investigated and found evidence of a variety of liquids in catchbasin. Spoke to persons responsible and made periodic checks.

June 1983. Culvert oily near auto repair shop. Shop connecting motor steam cleaning operation to sanitary system.

June 1983. Dump of about 25 gallons of hydraulic fluid into stormdrain. Truck operator billed for catchbasin cleanup ($250 for about 1-1/2 hours).

August 1983. Fish kill in Goff Creek. Found about 500 to 600 Cutthroat trout and Coho salmon, 10 eels, several salamanders and waterdogs, and many benthic organisms dead. Traced to a stormdrain discharge which only had about five inlets. Conflicting and fragmented reports of possible truck dumping in area. Several fish samples analysed for PCBs and pesticides. Typical concentrations were 100 to 300 ug/kg PCBs, 100 to 400 ug/kg toxaphene, and 100 to 400 ug/kg 4,4'-DDD. No formal conclusions.

August 1983. Diesel fuel spill from bus breakdown. Diesel flowed directly into stormdrain. Boom was placed in creek and bus company was to help in any needed cleanup operations.

August 1983. Malfuncting lawn sprayer discharged material into several catchbasins. City pumped out catchbasins and billed spraying company ($90 for about 1/2 hour).

August 1983. Apartment ponds treated with granular copper sulfate and Aquashade to control algae growths. The ponds are part of the city storm drainage system and are drained to public receiving waters. Discontinued practice pending waiver application.

Of the 50 reports summarized above, about 25 percent concerned oil being discharged into catchbasins. It is expected that many additional oil in catchbasin incidents occurred, but were not reported. Major receiving water problems, such as the large fish kill, are probably all reported. Aesthetic problems were also quite common. These problems included turbid stormwater outfalls, discolored creeks, and smelly nearshore lake areas. Many of these aesthetic problems were investigated with no apparent source found. Various industrial and commercial discharges into the stormdrains were detected. Concrete wastes flushed from concrete trucks at urban job sites were a reoccurring problem. Discharges from cleaning establishments into the stormdrains were also common, and have not been completely eliminated. Accidents were also fairly common. These involved spills of diesel fuel onto streets and into the inlets, and discharges of hydraulic fluids and lawn care chemicals into stormdrain inlets.

The Storm and Surface Water Utility responded to these citizen reports by conducting site investigations, initiating remedial clean-up operations, and with follow-up investigations. In many cases, they were able to eliminate the receiving water threat by cleaning the catchbasins or street surfaces. In some cases, booms were placed in the creeks to capture some of the material that was already flushed through the storm drainage. If they were responding to a receiving water problem complaint, effort was also made to identify the source of the offending material. They have an on-going public education program that encourages people to report any polluting activities. Many of their "talks" with people responsible for some of the pollution incidents were received with courtesy and cooperation. There have been some problems with repeat offenders that have not been resolved. It is very difficult to obtain evidence that can be used in an enforcement action.

Bellevue Storm and Surface Water
Programs and Policies

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Bellevue Storm and Surface Water Programs and Policies

A. INTRODUCTION

To understand how the City of Bellevue expects to incorporate the results of the National Urban Runoff Program (NURP) into public programs and policies necessitates an understanding of the Bellevue Storm and Surface Water (SSW) Utility. The Bellevue SSW Utility was formed out of a citizen and City commitment to preserve its network of streams and lakes. It was established in 1974 and given a mission to manage the storm and surface water system in Bellevue to maintain an hydrologic balance, to prevent property damage, and to protect water quality; for the health, safety and enjoyment of citizens and the preservation and enhancement of wildlife habitat. The basic concept underlying all policies and programs concerning storm water management in Bellevue is to use the natural surface water drainage system to provide for conveyance and disposal of storm water runoff. The SSW Utility system consists of an integrated network of pipes and stream channels which form the conveyance system; and lakes, wetlands, ponds and detention basins which are the storage facilities for flow equalization and some water quality control.

In carrying out its charge, the SSW Utility has four major programs: administration, development regulation, maintenance and operations, and a capital improvement program. The 1984 operating budget for funding these programs is $4.2 million. The 1980-1985 capital improvement budget is $13 million.

The major source of SSW Utility revenue is from a utility service charge. The rate structure currently is based on contribution of runoff to the drainage system. For a given storm event, a relationship exists between the amount of runoff from a property and land area, and in particular the impervious land area. Since runoff cannot practically be directly measured for all properties, this relationship is used to define the rate structure. All properties, including undeveloped and publicly-owned property, participate financially with such a structure since they contribute runoff and benefit from the SSW Utility programs.

Runoff coefficients are the basis of the five rate classifications: undeveloped (up to 0.25), light (0.25-0.4), moderate (0.4-0.5), heavy (0.5-0.75) and very heavy (0.75-1.0). The rate ordinances defining the structure are appended (Appendix A). Where runoff controls are provided on a property a commensurate rate reduction is granted.

During the initial five years of the SSW Utility the focus was almost exclusively on runoff volume and velocity, and erosion control. At the same time that the National Urban Runoff Program was being initiated the SSW Utility began to shift more attention to the water quality control aspects of its mission. In developing operations and maintenance programs and in designing the $13 million of capital improvement projects, the SSW Utility became aware of the need for more data, particularly in the Pacific Northwest region with its distinctive pattern of weather and land forms, and better information of storm water runoff quality controls. It was with these ends in view that Bellevue requested to become a NURP City. The results and conclusions recorded elsewhere in this report state what we have learned as a NURP participant. It is the purpose of this section to show how we intend to use what we learned.

B. POLICY APPLICATIONS

Policies relevant to storm water runoff quality in Bellevue are driven by the SSW Utility mission which articulates the need to protect storm water runoff quality for public health and safety concerns and beneficial uses. The beneficial uses of small urban streams and lakes which Bellevue seeks to preserve are, in order of priority, habitat, storm water conveyance, open space and resource preservation, recreation and aesthetics. (Bellevue's streams and lakes are not used as a drinking water source, as receiving waters for wastewater effluent, nor are they navigable). All of these beneficial uses were found to be degraded, to various extents, during the study.

Better knowledge of pollutant transport mechanisms allows a focussed approach to developing a water quality control strategy. Generally speaking, storm water pollutants originate at a source which, via runoff from precipitation, are transported into the street, then into the structural drainage system (inlets, catchbasins, pipes, detention systems) and finally into a Bellevue stream or lake. This chain may be foreshortened, e.g. the street is a source itself and a source may contribute directly to a drainage system or receiving water. With the objective in view of preserving or improving the quality of the receiving water, controls are possible at any one of these points. The following Bellevue NURP study findings indicate the expected success of some common control practices at these points:

(1) In general, the street surface and drainage system are not the major source of sediment or pollutants to receiving waters.

(2) While intensive street cleaning and drainage system cleaning does remove material from those areas it (a) preferentially removes larger, more inert particles, while storm water runoff removes smaller particles more highly associated with pollutants and (b) produces nonmeasurable effects on the quality of runoff.

(3) The use of on-site detention basins had no measurable effect on runoff quality.

(4) Kelsey Creek was seen to suffer more from frequent high flows, stream scour and erosion, sedimentation, and direct dumping of toxic materials than any other causes.

Based on these findings the SSW Utility has prioritized its direct actions to address the following identified problems:

(1) Toxic and hazardous materials dumping/spills

(2) Excess stream flows

(3) Sedimentation

(4) Lack of stream shade/stabilization

Management practices targeted on the street surface and structural drainage system, while having some merit, cannot provide a complete solution. An effective control strategy in Bellevue must look beyond the typical public works and utilities design, operations and maintenance practices to source controls, in-stream quantity and velocity controls, and even treatment.

In order to effect the necessary change in direction to accomplish this, Bellevue had to change the parent policy document for the City - its Comprehensive Plan. Over one hundred separate policies were consolidated to thirteen related to water quantity, quality, habitat, soil erosion and sediment control. Specific objectives with time lines and detailed implementation plans were included and related to the designated beneficial uses. Currently, the document is in draft form undergoing public review and is expected to be adopted close to its present form by the end of the year. The document (Appendix B) includes a discussion of intent and rationale based on the findings of the Bellevue NURP.

Concurrent with the drafting of the new policies a complete and detailed mapping of all wetlands, steep slopes, unstable soils and geologic areas was undertaken in the City and compiled into a Sensitive Area Notebook. These mapped sensitive areas, also currently in draft form awaiting formal adoption, accompany the policies and define where specific policies apply, e.g. wetlands or areas greater than 40% slope.

The new policies depart from past practices in very significant ways:

(1) They acknowledge that technology and enough funding cannot overcome any development problem or natural constraint.

(2) They place value on natural land forms and features, and seek to preserve them rather than treat all land as though it were dry and flat.

(3) Source controls for water quality, quantity and sediment are emphasized.

(4) The use of the best available technology is stated.

The implementation plans are intended to be complete guides of actions by the City to implement the policies. Elements appear each year in the City's, and specifically in the SSW Utility's, work programs for making progress toward the objectives and in accomplishing the tasks in the implementation plan.

C. PROGRAMS

Each of the SSW Utility's four major programs (administration, development regulation, operations and maintenance, capital improvement program) has been affected by the results of the Bellevue NURP.

1. Administration Program

The administration program handles primarily the financing policy and public involvement elements of the Utility. The policy element was discussed in the preceeding section. The financial aspects are covered in the following section on Budget.

From the SSW Utility's beginning it has sought and has been the focus of public attention. The impetus to establish the Utility generated from early citizen involvement. Members of the community interested in preserving Bellevue's lakes and streams asked the City Council in the late 1960's to find ways of allowing the City to grow without the sacrifice of these natural assets. This started a process involving three ad hoc citizen task forces working with the City over a period of seven years to address the issues. It was from these combined efforts that the basic framework and policies of the SSW Utility were established.

A key recommendation of the citizen groups was the establishment of a permanent Storm and Surface Water Utility Commission advisory to the City Council. Such a Commission was established in 1976. The SSW Utility continually assesses its performance in achieving its mission and objectives through the SSW Utility Commission. All rate, budget and policy matters are reviewed with the Commission. Periodic progress reports on the Bellevue NURP were made to the Commission over the period of the study. New policies, regulations, standards, and programs resulting from the Bellevue NURP all received substantial input from the Commission. The Commission continues to be the first line of citizen involvement on storm and surface water issues.

As part of the Bellevue NURP public participation task and together with a Municipality of Metropolitan Seattle (Metro) 208 funded program, Bellevue engaged in a four-year Salmon Enhancement Program for Kelsey Creek. There were several objectives to this program, in order of priority:

1. Public education on storm water runoff programs

2. Engendering a base of public support for water quality control programs

3. Re-establish salmon runs in the urban streams.

While the four-year program was not wholly successful in completely re-establishing salmon runs, the Salmon Enhancement Program in Bellevue was very successful in achieving the first two objectives as measured by the following events:

1. Wide spread public support for a highly controversial new Clearing and Grading Code in 1979.

2. Adoption of a Drainage Master Plan in 1980.

3. A 65% vote in favor of a $10 million revenue bond issue for Storm and Surface Water Utility capital improvements in 1980.

4. Wide spread public support for two large rate increases in 1980 and 1982 which were 170% and 80% respectively.

5. The establishment of a highly successful voluntary Oil Recycling Program in 1981.

6. An increase of 100% in water quality complaints during the period 1981-82 to 1982-83.

7. The citizen instigated naming of un-named creeks (e.g. Goff Creek) in 1982.

8. The adoption of a Private Maintenance Inspection Program in 1983.

Many of these milestones were achieved with the direct assistance of the Salmon Enhancement Program's Creeks Committee of Bellevue. This small but effective group spearheaded voluntary stream clean-up activities, constructed fishways, interacted with Bellevue schools in constructing salmon egg rearing boxes, staffed booths on urban stream public education at numerous fairs and shows, conducted streamside workshops, attended and actively participated in City Council meetings to support changes in codes, policies, regulations and the like, and actively campaigned in the election involving the SSW Utility $10 million bond issue. This small Committee played a truly activists role in support of preserving and enhancing Bellevue's urban streams.

Based on the success of this program the Storm and Surface Water Utility incorporated it as a Utility funded and ongoing program in 1984. The name was changed to the Stream Enhancement Program to broaden its scope beyond that of Salmon propagation and assigned to the Operations and Maintenance Program. Today this program is permanently staffed and charged to continue working with citizen action groups, Bellevue schools, corporate sponsors, community clubs and special interest groups to further public education on urban stream degradation, its prevention and cures, and to maintain and continue building the base of public support for and involvement in water quality and stream enhancement programs.

Two other key SSW Utility activities have proved valuable additions to the public education/involvement program: the Citizen Action Requests (CAR) response and SSW Utility tours. The CAR response function is handled by the Operations and Maintenance Program and is discussed in that subsection. The SSW Utility tours are open invitations to citizens and citizen groups to see first hand the physical elements of Utility programs and what they as ratepayers are receiving as benefits. These tours are tangible progress reports to the SSW Utility customers on its mission and objectives accomplishment. Nearly 100 tours have been given in the last four years to groups as diverse as the Bellevue Chamber of Commerce, the Steelheaders, and the League of Women Voters. Tours have also been given to officials from other municipalities interested in forming drainage utilities and/or for those whom Bellevue wishes to enter into interlocal agreements for storm water control in drainage basins crossing jurisdictional boundaries. To date Bellevue has entered into two such agreements. One with King County for the Coal Creek basin and one with the Cities of Redmond and Issaquah, King County and Metro for water quality improvements in Lake Sammamish. These activities tie-back directly to the policy implementation plans.

2. Development Regulation Program

The development regulation program involves reviewing all Building Permits, plats, short plats, planned unit developments and rezones, issuing all Clearing and Grading Permits for drainage and erosion control and performing inspections on same. The new policies discussed in the previous section, when adopted, will significantly refocus this program. Revisions to the existing Clearing and Grading Code, Floodplain Management Code, Land Use Code and Subdivision Code are anticipated within the next year. Concurrently new drainage regulations and design standards will be adopted to fully implement the changes in direction.

Examples of specific changes expected are mandatory setbacks from streams, slopes and wetlands; criteria for when a stream is degraded and detailed requirements for restoration; seasonal limits on land alteration activities; prohibition of the outdoor storage of potentially polluting and toxic materials and requirements for the provision of secondary containment in loading areas for same; mandatory contingency plans for spills or accidents involving hazardous materials; more rigorous methods for sizing and designing on-site detention systems; and requirements for on-site treatment of polluted storm water runoff before discharging to an off-site drainage system or any receiving water.

Once the new policies, codes, regulations and standards are in place the development regulation program will carry them out through its permiting and inspection functions. All these elements are planned to be consolidated in a Storm and Surface Water Manual for ease of use. Again, these activities tie-back directly to the policy implementation plan.

3. Capital Improvement Program

The capital improvement program plans, designs and constructs all major facilities for the SSW Utility. This program was significantly changed based on the Bellevue NURP finding that frequent high flows, due to small storms, stream scour and erosion, and sedimentation were largely responsible for the degraded character of Kelsey Creek. Preliminary design of improvements, prior to 1980, were based on controlling only the larger storm flows, generally greater than the 10-year event in occurence, for flood control purposes. This was done by the design of twenty large regional in-stream detention facilities. Bellevue NURP preliminary findings indicated by 1981 that storm water flow controls were needed for the more frequent storms (e.g. 30 events per year in occurence) to improve stream quality and habitat. In 1981 design of all the Kelsey Creek improvements was redirected to accomplish this. The design and subsequent operation of the facilities was made more complex in order to achieve the double and sometimes competing objectives of maintaining enough facility capacity to accommodate large storms to prevent flooding and property damage (i.e. have the regional facilities usually empty) and utilizing capacity on smaller storms to preserve and improve stream habitat (i.e. have the regional facilities frequently full or in partial use).

In order to manage this problem as well as to provide adequate coordination of release rates among all the facilities a semi-automated operating system was designed and each facility was provided with at least one and sometimes several emergency overflows. The system involves a network of rain gauges, flow gauges up and downstream from each facility, a telemetering system to transmit the data instantaneously and continuously to a central monitoring location equipped with alarms, for imminent overflow and malfunctions, and remote controlled facility release rate operation. The gauges are currently being installed and remote operations are anticipated to be functional by winter, 1985. Thereafter, a one-year shake-down period is planned, the results of which will be documented in the operations and maintenance manual for the system.

The seven facilities already constructed should mitigate the high stream flow problems identified in the Bellevue NURP study, and provide sites for sedimentation removal. Fish passage facilities were also appropriately provided. Since several of the sites are natural wetlands, there should be some added water quality benefits from wetland treatment. The SSW Utility is revising its Comprehensive Drainage Plan and capital improvement program in 1984 to evaluate the remaining facilities to be constructed in light of new information provided by the Bellevue NURP and the new policies discussed in the previous section.

4. Operations and Maintenance Program

The operations and maintenance (O&M) Program is responsible for the cleaning, repair and minor replacement of the SSW Utility's physical system; operates all the Utility's regional detention facilities including the telemetering system; records and responds to all Customer Action Requests; is responsible for water quality control functions; handles the stream enhancement program and does private maintenance inspections. Each one of these functions has been modified in view of the Bellevue NURP findings.

As part of the Bellevue NURP, a study of all the Utility's maintenance practices and standards was done by a team of consultants. The objective was to analyze the maintenance activities, costs, and expected effects to develop the most cost effective overall program to achieve the water quality objectives. Based on the consultant study and the Bellevue NURP results O&M standards for both public and private drainage facilities were adopted. Budget, staffing, and equipment changes were made in 1983 to provide resources to accomplish the standards on the public system, i.e. SSW Utility System. Also in 1983 the Utility was empowered to perform inspections on privately operated and maintained facilities to assure compliance with the adopted O&M standards. These two activities are intended to achieve the 10-25% improvement in water quality projected in the Bellevue NURP results at reasonable cost.

The O&M program performs all operations of the regional detention facilities constructed by the capital improvement program. As such, staff are on call 24-hours a day, 7-days a week to respond to storm emergencies. While computer assistance is used, all decisions on facility release rates and reservoir routing are made by the O&M staff in addition to doing the system inspections and routine maintenance. The O&M manual for the detention and telemetry system is currently in draft form and includes provisions for routine inspection of the facilities, and exercising and testing the system periodically (similar to the fire hydrant and sewer pump station exercise and inspection programs) to insure its function, and the removal of accumulated sediment and debris. The Washington State Department of Fisheries and the SSW Utility have agreed upon operating criteria to promote the migration through the facilities of indigenous fish populations while maintaining protection of the downstream reaches. The telemetry and remote control operating system allows for maximum control with a minimum of staff thereby reducing costs.

O&M staff respond to all Citizen Action Requests (CARs). The CAR (Appendix C) is a way of recording and tracking any citizen request made of the Utility, e.g. flooding and water quality complaints.

Prompt action by the SSW Utility in responding to the request and checking back with the requestor for satisfaction has engendered enormous public support and is gradually changing citizen attitudes about the worth of reporting problems. In 1983 the following water quality complaints were received:

1. Four fish kills and two other wildlife kills.
2. Nine spills of oil or hazardous substances.
3. Thirteen discharges of pollutants by commercial concerns.
4. Four sewage discharge incidents and two discharges of swimming pool filter backwash.
5. Seventeen incidents of stream or lake discoloration or turbidity.
6. Five incidents of oil disposal in catchbasins.
7. Three information requests on potential water quality violations or problems.

It is probable that such incidents were equally common in the past but went unnoticed or uncared for. The recent increase in water quality complaints is attributed to heightened public awareness and concern resulting from the SSW Utility's public education/involvement activities and responsiveness to CARs.

All water quality control functions are the responsibility of the O&M Program. This includes a routine monitoring program of stream quality for temperature, pH, specific conductance and turbidity, and investigative monitoring to locate and identify specific sources of pollutants. This latter task includes the coordination with other organizations and agencies such as the Fire Department, Metro, the King County Health Department, the Washington State Departments of Ecology and Fisheries and the Environmental Protection Agency. Because the prevention and mitigation of toxic and hazardous materials dumping and spills are such a high priority for stream protection this part of the program has been emphasized increasingly since 1980. Although progress has been impressive, the SSW Utility's efforts continue to be frustrated by the lack of adequate enforcement against violators because (1) Bellevue lacks the authority and (2) pollution cases of this type are usually difficult to prove.

The former problem may be resolved by a proposed new State program. The Washington State Department of Ecology has approached the City of Bellevue's SSW Utility as being the recipient of a pilot General National Pollutant Discharge Elimination System (NPDES) Permit for storm water runoff quality control. The permit is expected to be issued in 1984. It is anticipated that such a permit would increase the authority of the SSW Utility to enforce water quality standards at the local level. The permit is also expected to mandate certain specific management practices and some monitoring. The SSW Utility will increase its water quality monitoring program to include additional impervious surface and limited storm water monitoring in land use areas which were not included in the Bellevue NURP Study to test the assumption that the study conclusions apply to all areas within Bellevue. Continuous remote monitoring of one or more simple parameters such as turbidity or temperature is also being considered as a warning system of stream pollution problems.

The stream enhancement program was previously described under the Administration program section as part of the overall public education/involvement program.

D. BUDGET

During the period of the Bellevue NURP study the SSW Utility's annual revenues increased from $625,000 in 1979 to $4.2 million in 1984. The growth was largely due to the $13 million capital improvement program financing. Also during the same period the accounting system for the SSW Utility was completely revised and a Rate Study was conducted in 1981-1982. These activities were influenced by the Bellevue NURP Study.

1. Storm and Surface Water Utility Rates

As stated in the Introduction, the SSW Utility rates have been and are currently based on runoff rate as determined by the amount of impervious surface and total property area. A key question posed during the Rate Study was whether rates could or should be based also on runoff quality.

Utility rates are derived from the cost of service to different customer classes. In order to determine these costs they must be accounted for within specific cost centers, e.g. billing costs, O&M costs, capital costs, etc. During the Rate Study it was discovered that the SSW Utility O&M expenditures were lumped and costs associated with water quality activities could not be segregated. As a result no analysis could be made at that time of costs of service apportionment on the basis of water quality. Subsequently, the accounting system was completely revised beginning in 1983 to collect the necessary cost data such that the analysis could be made in the 1985 Rate Study.

Analysis only will not answer the question of whether rates should be apportioned on the basis of water quality. The types of SSW Utility activities which are included in the water quality cost center are cleaning of the drainage system (inlets, catchbasins, manholes, detention facilities and pipes), water quality monitoring, the emergency response program for pollution events and spills, a portion of the private maintenance inspection program and the stream enhancement program.

One difficulty is directly relating some of these activities to specific customer classes. Since the Bellevue NURP studied only street surfaces and the drainage system as sources in a limited number of land use areas there is insufficient data to estimate loads from off-street areas and other land uses as yet unanalyzed (e.g. commercial, industrial, multifamily, construction sites, agricultural, open space). Bellevue NURP data did strongly indicate, however, that off-street areas contributed significantly to some parameter loadings, and in particular were the major source of total solids. The water quality monitoring element of the O&M program is currently collecting samples on different land use areas to fill this data gap.

If a general relationship could be made between land use type or customer classification and average loading of some target pollutant, e.g. total solids, then rates could also be made a function of runoff quality as well as runoff rate. The amount apportioned to the quality function would be set at the total revenue requirement for water quality activities. The theory behind such a cost apportionment is that at some point pollutants from each customer class leave the property to become a public problem, either via the SSW Utility structural drainage system or directly to receiving waters. Similar to granting a rate reduction to those customers providing on-site runoff rate control, a rate reduction could be granted to those customers providing on-site storm water treatment or other water quality controls. In this way the rates would provide incentives for source controls, one of the objectives of the new water quality control policy. While the Bellevue SSW Utility does not now have such a rate structure, much of the necessary data to evaluate such a proposal will be available for the next Rate Study in 1985.

2. Storm and Surface Water Utility Budget

The increase in SSW Utility revenues combined with the Bellevue NURP study findings and the success of the Salmon Enhancement Program have provided the necessary resources and direction to adequately fund SSW Utility water quality control programs. The O&M budget for water quality control programs was $250,308 and $280,306 for 1983 and 1984 respectively. A new Vactor was purchased in 1983 to clean the structural drainage system more effectively and frequently. Two new O&M programs were funded which deal directly with water quality: the private maintenance inspection program (1984 budget: $17,385) and the stream enhancement program (1984 budget: $25,671). The water quality monitoring program increased from $31,170 in 1983 to $40,647 in 1984. The capital improvements program was funded at a sufficient level that water quality control and stream enhancement features were able to be added to the flood control facilities.

It is because there is a SSW Utility in Bellevue that such programs can be adequately funded. Urban runoff quality is generally such a low priority compared to other municipal programs (e.g. police, fire, transportation, etc.) that reliance on general tax based revenues for support is unfeasible. Only a sacrosanct, designated revenue source can guarantee stable financing of a comprehensive storm and surface water management program.

E. SUMMARY

The Bellevue NURP study findings identified the need to look beyond the typical public works and utilities practices to effect urban runoff quality controls, since most pollutants originate off-street. Source controls, prevention and even treatment were indicated. Additionally, the urban stream studied, which is typical for Bellevue, was shown to be degraded largely by runoff quantity and velocity effects.

To address these problems Bellevue has taken a multifaceted approach starting with a complete revision of its Comprehensive Plan policies. Specific problems identified in the Bellevue NURP study were prioritized for action and new policies written for each.

Storm and Surface Water Utility programs were re-evaluated and revamped to assure that the prioritized problems were being addressed:

(a) Toxic and hazardous materials dumping/spills - The O&M program modified its functions to monitor, coordinate, respond, enforce and educate offenders in this area; the administration program involves and educates the public.

(b) Excess stream flows - The capital improvement program revised plans, designs and construction of public facilities to control excessive stream flows for habitat reasons as well as flood control; the O&M program operates and maintains these facilities for same; the development regulation program controls private connections to the system and imposes restrictions to avoid overburdening system capacity.

(c) Sedimentation - The O&M program removes sediment and other pollutants from the drainage system according to newly adopted O&M standards, as well as inspects private systems for same; the development regulation program controls erosion from land alteration activities.

(d) Lack of stream shade/stabilization - the new stream enhancement program works with both public organizations and private individuals to restore and preserve riparian vegetation and construct where necessary stabilizing measures.

Finally, water quality control activity costs have been segregated for accounting purposes to allow for future apportionment to SSW Utility customers through the rate structure to provide incentives for source controls, and sufficient budget has been allocated to water quality control programs. Continued monitoring over future years will assess whether these management practices in fact achieve the SSW Utility's goal to protect storm water runoff quality for public health and safety concerns and beneficial uses.

CITY OF BELLEVUE, WASHINGTON

ORDINANCE NO. 3080

AN ORDINANCE increasing storm and surface water drainage service charges for the Storm and Surface Water Utility of the City of Bellevue, and amending Section 4 of Ordinance No. 2429.

WHEREAS, by Ordinance No. 2003, the City Council created and established a Storm and Surface Water Utility to administer, own and operate the City's storm and surface water public facilities; and

WHEREAS, the Storm and Surface Water Utility has caused to be prepared a Storm and Surface Water Drainage Master Plan for the acquisition, construction and operation of the storm and surface water system of the City, hereinafter referred to as the "Plan of Addition and Betterments," and

WHEREAS, the City Council adopted and approved the Plan of Additions and Betterments by Ordinance No. 2798, and also therein called for a special election to be conducted within the City for the purpose of submitting to the electorate of the City an advisory ballot as to whether the voters favor the capital improvements contained in the Plan of Additions and Betterments, to be funded in whole or in part by revenue bonds payable from service charges; and

WHEREAS, on March 18, 1980 such special election was held with a majority voting in favor of the proposition on the advisory ballot; and

WHEREAS, administrative officials of the City have been authorized and directed to implement Phase I of the Plan of Additions and Betterments, and

WHEREAS, the cost of carrying out Phase I shall be paid for by the issuance, pursuant to RCW Chapters 35.41 and 35.67, of approximately $10,000,000 par value of revenue bonds in one or more issues, payable from service charges; and

WHEREAS, it is necessary to increase the Storm and Surface Water Utility service charges in order to fund the first and second issues of revenue bonds, now therefore,

THE CITY COUNCIL OF THE CITY OF BELLEVUE, WASHINGTON, DOES ORDAIN AS FOLLOWS:

Section 1. Section 4 of Ordinance No. 2429 as amended is hereby further amended to read as follows:

There is hereby levied upon all real property within the City of

Bellevue which contributes drainage water to or which benefits from the function of the Storm and Surface Water Utility of the City of Bellevue, and there shall be collected from the owners thereof, monthly service charges based on the square footage of the properties and on the appropriate intensity of development classification(s) of such properties, such that for each 2,000 square feet of area or increments thereof, the property shall be charged an amount per month as follows:

Undeveloped	Light Development	Moderate Development	Heavy Development	Very Heavy Development
$0.10	$0.60	$0.75	$1.12	$1.50

and each account shall be charged an additional customer charge in the amount of $0.66 per month, and there shall be collected from the owners of undeveloped properties which become developed a "late-comer" facilities charge of $11.65 per equivalent billing unit per year from March 1, 1982 to date of development, pro-rated on a monthly basis. An equivalent billing unit shall be defined as the number of square feet of property divided by 2,000 square feet times the runoff coeffecient associated with the newly developed property's intensity of development classification. The runoff coefficient for the respective development classifications are defined as follows: Undeveloped: 0.25; Light Development: 0.4; Moderate Development: 0.5; Heavy Development: 0.75; Very Heavy Development: 1.00.

The rates and charges established herein shall be reevaluated no later than five years from March 1, 1982.

Section 2. The revised monthly service charges, monthly customer charge and late-comer facilities charge, herein established shall take effect on March 1, 1982.

Section 3. This ordinance shall be published by posting it in the three official posting places of the City, and shall take effect and be in force five days after the date of posting.

PASSED by the City Council this 8 day of February, 1982, and signed in authentication of its passage this 8 day of February, 1982.

(SEAL)

Roy A. Ferguson
Roy A. Ferguson, Mayor

Approved as to form:

William C. Graves
William C. Graves, Assistant City Attorney

Attest:

Patricia K. Weber
Patricia K. Weber, City Clerk

Published February 10, 1982

CITY OF BELLEVUE, WASHINGTON

ORDINANCE NO. 3372

AN ORDINANCE relating to service charges for the Storm and Surface Water Utility of the City, authorizing service charge increases for certain real property within the Meydenbauer Drainage Basin; and authorizing general facilities charges for properties not subject to storm water detention requirements.

WHEREAS, on September 12, 1983, the City Council adopted Resolution No. 4239, adding the Meydenbauer Drainage Trunkline Project to the City's 1983-87 Capital Improvement Program (C.I.P.); and

WHEREAS, the City has allocated $400,000 from the Drainage Utility Fund to pay for its share of the cost of said project; and

WHEREAS, on September 12, 1983 the City Council created the Meydenbauer Drainage Trunkline Finance Committee to study and make recommendations regarding methods of financing the unfunded portion of the cost of constructing the project; and

WHEREAS, on October 17, 1983 the City Council adopted Ordinance No. 3304, ordering construction of a portion of said project, and creating L.I.D. 265 to pay for a portion of the cost thereof; and

WHEREAS, the Meydenbauer Drainage Trunkline Finance Committee met for a period of six weeks during the months of September, October and November, 1983, and, after having considered various alternatives, presented to the City Council its recommended financing plan for the unfunded portion of the cost of the project, including proposed policies for construction of lateral connections to said trunkline; and

WHEREAS, the City Council has considered the recommendations of the Finance Committee, as well as other possible methods of financing the project, and determined that the Committee's recommendations should be adopted; and

WHEREAS, on December 12, 1983 the City Council adopted Resolution No. 4286 adopting a plan for financing the unfunded construction costs of the Meydenbauer Drainage Trunkline; and

WHEREAS, by Section 6 of Resolution No. 4286 adopted on December 12, 1983, the City Council provided that it shall by Ordinance establish the rates and charges to be imposed upon property within that portion of the Meydenbauer Drainage Basin lying within the City as necessary to provide the monies set forth in Section 1, subsections A. and B., and Section 2 of Resolution No. 4286; and

WHEREAS, the payment by the City of $400,000 from the Drainage Utility Fund to pay for its share of the project shall be in lieu of any service charge increase to City right-of-way or easements within the project area; and

WHEREAS, by creating the "No Detention Zone" within the Meydenbauer Drainage Basin the City has relieved property owners from the requirement of providing storm drainage detention facilities, thereby benefitting such properties and correspondingly increasing the City's expense in providing storm drainage service to such properties; and

WHEREAS, the Meydenbauer Drainage Trunkline Project will provide direct drainage service to those properties within the "Local Service Zone" and will provide a storm drainage system with an upgraded design for a 100 year flood thus reducing potential flooding damage to such properties; and

WHEREAS, a public hearing was held on December 12, 1983 concerning the financing of the Meydenbauer Drainage Trunkline Project and public comment and recommendation was solicited; now, therefore,

THE CITY COUNCIL OF THE CITY OF BELLEVUE, WASHINGTON, DOES ORDAIN AS FOLLOWS:

Section 1. In addition to any service charge or customer charge levied pursuant to Section 4 of Ordinance No. 2429, as amended, there is levied upon all real property within the Central Business District (CBD), as defined by BCC 20.50.010, lying west of 108th Avenue N.E. and draining to the Meydenbauer Drainage Basin, a service charge of .0737 ¢ per square foot per month. The area defined in this section shall hereinafter be termed the "No Detention Zone."

Section 2. In addition to any service charge or customer charge levied pursuant to Section 4 of Ordinance No. 2429, as amended, and in addition to any charge levied pursuant to Section 1 of this Ordinance there is hereby levied on all real property within the Central Business District (CBD) as defined by BCC 20.50.010, lying west of 108th Avenue N.E. and draining to the Meydenbauer Drainage Basin and exclusive of that area within the CBD lying south of N.E. 8th Street and west of Bellevue Way and exclusive of that area within the CBD lying south of N.E. 2nd and east of Bellevue Way, a service charge of .1360 ¢ per square foot per month. The area defined in this section shall hereinafter be termed the "Local Service Zone."

Section 3. In determining the square footage of any property subject to service charges levied by Sections 1 and 2 of this Ordinance there shall be deducted any square footage subject to a recorded City drainage easement and/or right-of-way granted to and accepted by the City or its predecessor.

Section 4. In addition to any general facilities charge imposed pursuant to Section 4 of Ordinance No. 2492, as amended, a general facilities charge shall be imposed at the time of development or redevelopment upon all those properties within the Meydenbauer Drainage Basin excluding those properties within Local Improvement District No. 265 (Gateway Properties) and those properties within the "No Detention Zone." Such charge shall be at a rate of 6.404 ¢ per square foot indexed to the time of development or redevelopment using the Engineering News Record Cost of Construction Index for Seattle.

Section 5. A general facilities charge of $ 79.69 per linear foot of replacement line shall be imposed at the time of development or redevelopment upon all those properties within the Central Business District (CBD), lying between N.E. 2nd Street and N.E. 12th Street, through which the replacement drainage line is located. Such charge shall be indexed at the time of development or redevelopment using the Engineering News Record Cost of Construction Index for Seattle. Such linear footage charge shall be based on the straightline distance between the points where the replacement line intersects the respective property lines.

Section 6. Any property owner who pays directly for the cost of completion of any portion of the Meydenbauer Drainage Trunkline shall, upon acceptance thereof by the City, be entitled to a credit for the amount paid to construct such portion of the Trunkline against the present value of any general facilities charge or service charge imposed upon such property owner's property by this Ordinance, computed as of the time of such payment; provided, however, that such credit shall not exceed the total of the then present value of all general facilities charges and/or service charges imposed upon such property by this Ordinance.

Section 7. The service charges set forth in Sections 1 and 2 of this Ordinance and the general facilities charges set forth in Sections 4 and 5 of this Ordinance shall take effect on June 1, 1984.

Section 8. This Ordinance shall be published in the three official posting places of the City, and shall take effect and be in force five days after the day of posting.

PASSED by the City Council this 7th day of May, 1984, and signed in authentication of its passage this 7th day of May, 1984.

(SEAL)

Cary B

Cary E. Bozeman, Mayor

Approved as to form:

Richard L. Andrews, Acting City Attorney

Richard L. Kirkby, Assistant City Attorney

Attest:

Marie K. O'Connell

Marie K. O'Connell, City Clerk

Published May 13, 1984

2577
5/25/78

CITY OF BELLEVUE, WASHINGTON

ORDINANCE NO. 2577

AN ORDINANCE relating to rate classification and service charges for the Storm and Surface Water Utility of the City, authorizing certain rate classification adjustments, and amending Sections 3 and 4 of Ordinance No. 2429.

THE CITY COUNCIL OF THE CITY OF BELLEVUE, WASHINGTON, DOES ORDAIN AS FOLLOWS:

Section 1. Section 3 of Ordinance No. 2429 is hereby amended to read as follows:

> Section 3. The City Council finds that some properties, due either to their unique topographical, vegetative, surficial geologic, soil moisture and/or ground water characteristics, or to the construction and maintenance of storm and surface water control or detention facilities thereon, have a hydrologic response substantially similar to properties of a lower classification of intensity of development as defined in Section 2. The Storm and Surface Water Utility may classify an individual parcel of property to a classification different than would be indicated by its percentage of impervious surfaces based on hydrologic data to be submitted by the property owner or his agent to the said utility, which demonstrates a hydrologic response substantially similar to that of a parcel of property of a different classification set forth in Section 2.
>
> The City Council further finds that, in the case of some parcels of property of more than 44,000 square feet in size, in addition to the conditions set forth in paragraph 1 of this section, there may be intensities of development on portions of such parcels of property which differ significantly from other portions of such property in terms of hydrologic response. To provide for consideration of the variation in intensity of development which may be present on such parcels of property, the Storm and Surface Water Utility may classify portions of such parcels of property in any of the classifications defined in Section 2 on the basis of hydrologic response. Provided, however, that at least 44,000 square feet shall be classified in the most intense classification appropriate to a portion of the parcel of property.

Section 2. Section 4 of Ordinance No. 2429 is hereby amended to read as follows:

> Section 4. There is hereby levied upon all real property within the City of Bellevue which contributes drainage water to or which benefits from the function of the storm and surface water utility the City of Bellevue which contributes drainage water to or which

benefits from the function of the storm and surface water utility of the City of Bellevue, and there shall be collected from the owners thereof, monthly service charges based on the square footage of the properties and on the appropriate intensity of development classification(s) of such properties, as follows:

TOTAL SQUARE FEET OF PROPERTY		INTENSITY OF DEVELOPMENT CLASSIFICATIONS			
	UNDEVELOPED	LIGHT DEVELOPMENT	MODERATE DEVELOPMENT	HEAVY DEVELOPMENT	VERY HEAVY DEVELOPMENT
0-2000	$ .08	$ .12	$ .16	$ .23	$ .31
2-4000	.16	.23	.31	.47	.62
4-6000	.23	.35	.47	.70	.94
6-8000	.31	.47	.62	.94	1.25
8-10,000	.39	.59	.78	1.17	1.56
10-12,000	.47	.70	.94	1.40	1.87
12-14,000	.55	.82	1.09	1.64	2.18
14-16,000	.62	.94	1.25	1.87	2.50
16-18,000	.70	1.05	1.40	2.11	2.81
18-20,000	.78	1.17	1.56	2.34	3.12
20-22,000	.86	1.29	1.72	2.57	3.43
22-24,000	.94	1.40	1.88	2.81	3.74
24-26,000	1.01	1.52	2.03	3.04	4.06
26-28,000	1.09	1.64	2.19	3.28	4.37
28-30,000	1.17	1.76	2.34	3.51	4.68
30-32,000	1.25	1.87	2.50	3.74	4.99
32-34,000	1.33	1.99	2.66	3.98	5.30
34-36,000	1.40	2.11	2.81	4.21	5.62
36-38,000	1.48	2.23	2.97	4.45	5.93
38-40,000	1.56	2.34	3.12	4.68	6.24
40-42,000	1.64	2.46	3.28	4.91	6.55
42-44,000	1.72	2.57	3.44	5.15	6.86
44-46,000	1.79	2.69	3.59	5.38	7.18
46-48,000	1.87	2.81	3.75	5.62	7.49
48-50,000	1.95	2.96	3.90	5.85	7.80
50-52,000	2.03	3.04	4.06	6.08	8.11
52-54,000	2.11	3.16	4.21	6.32	8.42
54-56,000	2.18	3.28	4.37	6.55	8.74
56-58,000	2.26	3.39	4.53	6.79	9.05
58-60,000	2.34	3.51	4.68	7.02	9.36
60-62,000	2.42	3.63	4.84	7.25	9.67
62-64,000	2.50	3.74	5.00	7.49	9.98
64-66,000	2.57	3.86	5.15	7.72	10.30
66-68,000	2.65	3.98	5.31	7.96	10.61
68-70,000	2.73	4.10	5.46	8.19	10.92
70-72,000	2.81	4.21	5.62	8.42	11.23
72-74,000	2.89	4.33	5.78	8.66	11.54
74-76,000	2.96	4.45	5.93	8.99	11.86
76-78,000	3.04	4.56	6.09	9.13	12.17
78-80,000	3.12	4.68	6.24	9.36	12.48
80-82,000	3.20	4.80	6.40	9.59	12.79

82-84,000	3.28	4.91	6.56	9.83	13.10
84-86,000	3.35	5.03	6.71	10.06	13.42
86-88,000	3.43	5.15	6.87	10.30	13.73
88-90,000	3.51	5.27	7.02	10.53	14.04
90-92,000	3.59	5.38	7.18	10.76	14.35
92-94,000	3.67	5.50	7.34	11.00	14.66
94-96,000	3.74	5.62	7.49	11.23	14.98
96-98,000	3.82	5.73	7.65	11.47	15.29
98-100,000	3.90	5.85	7.80	11.70	15.60

and for each additional 2000 square feet of area or increments thereof, and in accordance with the intensity of development classification of the property, the property shall be charged an additional amount per month as follows:

UNDEVELOPED	LIGHT DEVELOPMENT	MODERATE DEVELOPMENT	HEAVY DEVELOPMENT	VERY HEAVY DEVELOPMENT
.078	.117	.156	.234	.312

Section 3. This ordinance shall take effect and be in force on July 1, 1978.

PASSED by the City Council this 30 day of May, 1978, and signed in authentication of its passage this 30 day of May, 1978.

(SEAL)

Gary A Zimmerman
Gary A. Zimmerman, Mayor

Approved as to form:

Lee Kraft
Lee Kraft, City Attorney

Attest:

Patricia K Weber
Sharon Stewart, Deputy City Clerk

Published June 3, 1978

2429
5-27-77

CITY OF BELLEVUE, WASHINGTON

ORDINANCE NO. 2429

AN ORDINANCE establishing rate classifications and service charges for the Storm and Surface Water Utility of the City of Bellevue.

WHEREAS, by Ordinance No. 2003 the Storm and Surface Water Utility of the City of Bellevue was established, and the City transferred to said utility the City's storm and surface water sewerage system; and

WHEREAS, by Resolution No. 2802 the City Council established a Storm and Surface Water Advisory Commission to review, advise and make recommendations to the City Council regarding, among other items, storm and surface water rate structures; and

WHEREAS, said Commission by its "Report on Utility Rate Structure", dated March 14, 1977, has recommended to the City Council a proposed rate structure; and

WHEREAS, the City Council has reviewed said report and the utility rate structure therein recommended, and concurs therewith; and

WHEREAS, the City Council finds that all real property in the City contributes runoff to common drainage systems, and all property in the City benefits from the Storm and Surface Water Utility System of the City of Bellevue, and therefore should participate financially in payment of the expenses for the maintenance, operation and improvement of said system; and

WHEREAS, the City Council finds that the intensity of development of real property and the area thereof are the primary factors in an individual property's contribution of total and peak flows of storm water runoff to the said utility system; now, therefore,

THE CITY COUNCIL OF THE CITY OF BELLEVUE, WASHINGTON, DOES ORDAIN AS FOLLOWS:

Section 1. Definitions. The following words when used herein shall have the meanings indicated, unless the context clearly indicates otherwise:

a. Hydrologic Response - The manner and means by which storm water collects upon real property and is conveyed from real property, and which is a function dependent upon a number of interacting factors, including, but not limited to, topography, vegetation, surficial geologic conditions, antecedent soil moisture conditions and ground water conditions. The principal measures of the hydrologic system may be stated in terms of total runoff volume, as a percentage of total precipitation which runs off, or in terms of the peak rate of flow generated in the event of a storm of given duration and intensity, or statistical interval of return (frequency).

b. Total Flow - The accumulative volume of water discharged from a property, basin, or water shed. The total flow is quantified in measures such as gallons or cubic feet of water.

c. Peak Flow - The highest momentary rate of water flow, measured or estimated in cubic feet of water per second or gallons of water per minute. It is differentiated from total flow volume by the introduction of a unit of time measure during which the maximum rate of flow is measured, calculated, or estimated.

d. Contributors of Drainage Waters - Shall include all real properties within the City from which flows storm or surface waters, or waters supplied by Municipal or private sources which exit the property as surface flows and/or enter the storm and surface water utility system of the City of Bellevue.

e. Beneficiaries of Drainage Service - Shall include all real properties within the City of Bellevue which benefit by the provision, maintenance, operation and improvement of the storm and surface water control system by the City of Bellevue, regardless of how that system may be constituted. Such benefits may include, but are not limited to, the provision of adequate systems of collection, conveyance, detention, treatment and release of storm water, the reduction of hazard to property and life resulting from storm water runoff, improvement in the general health and welfare through reduction of undesirable storm water conditions, improvements in the water quality in the storm and surface water system and its receiving waters, and the limitation of potentially harmful land uses and land alteration activities which might otherwise negatively impact the storm and surface water system.

f. Impervious Surfaces - Those hard surfaced areas which either prevent or retard the entry of water into the soil mantle, as it entered under natural conditions pre-existent to development, and/or cause water to run off the surface in greater quantities or at an increased rate of flow from that present under natural conditions pre-existent to development. Common impervious surfaces include, but are not limited to, rooftops, concrete or asphalt sidewalks and paving, walkways, patio areas, driveways, parking lots or storage areas and gravel, oiled, macadam or other surfaces which similarly impact the natural infiltration or run-off patterns which existed prior to development.

Section 2. All real property in the City of Bellevue shall be classified by the Storm and Surface Water Utility according to the square footage of area of the property and the intensity of development set forth below:

a. Undeveloped - Real property which is undeveloped and unaltered by buildings, roads, impervious surfaces or other physical improvements which change the hydrology of the property from its nature state.

b. Light Development - Developed real property which has impervious surfaces of less than 20% of the total square footage area of the property.

c. Moderate Development - Developed real property which has impervious surfaces between 20% and 40% of the total square footage area of the property.

d. Heavy Development - Developed real property which has impervious surfaces between 40% and 70% of the total square footage area of the property.

e. Very Heavy Development - Developed real property which has impervious surfaces of more than 70% of the total square footage area of the property.

Section 3. It is recognized that some properties, due either to their unique topographical, vegetative, surficial geologic, soil moisture and/or ground water characteristics, or to the construction and maintenance of storm and surface water control or detention facilities thereon, have a hydrologic response substantially similar to properties of a lower classification of intensity of development.

The Storm and Surface Water Utility may adjust the intensity of development classification of an individual parcel of property to a classification different than would be indicated by its percentage of impervious surfaces based on hydrologic data to be submitted by the property owner or his agent to the said utility, which demonstrates a hydrologic response substantially similar to that of a property of a different classification set forth in Section 2.

Section 4. There is hereby levied upon all real property within the City of Bellevue which contributes drainage water to or which benefits from the function of the storm and surface water utility of the City of Bellevue, and there shall be collected from the owners thereof, monthly service charges based on the square footage of the properties and on the appropriate intensity of development classification of such properties, as follows:

TOTAL SQUARE FEET OF PROPERTY		INTENSITY OF DEVELOPMENT CLASSIFICATIONS			
	UNDEVELOPED	LIGHT DEVELOPMENT	MODERATE DEVELOPMENT	HEAVY DEVELOPMENT	VERY HEAVY DEVELOPMENT
0-2000	$ .08	$ .12	$ .16	$ .23	$ .31
2-4000	.16	.23	.31	.47	.62
4-6000	.23	.35	.47	.70	.94
6-8000	.31	.47	.62	.94	1.25
8-10,000	.39	.59	.78	1.17	1.56
10-12,000	.47	.70	.94	1.40	1.87
12-14,000	.55	.82	1.09	1.64	2.18
14-16,000	.62	.94	1.25	1.87	2.50
16-18,000	.70	1.05	1.40	2.11	2.81
18-20,000	.78	1.17	1.56	2.34	3.12
20-22,000	.86	1.29	1.72	2.57	3.43
22-24,000	.94	1.40	1.88	2.81	3.74
24-26,000	1.01	1.52	2.03	3.04	4.06
26-28,000	1.09	1.64	2.19	3.28	4.37
28-30,000	1.17	1.76	2.34	3.51	4.68
30-32,000	1.25	1.87	2.50	3.74	4.99
32-34,000	1.33	1.99	2.66	3.98	5.30
34-36,000	1.40	2.11	2.81	4.21	5.62
36-38,000	1.48	2.23	2.97	4.45	5.93
38-40,000	1.56	2.34	3.12	4.68	6.24
40-42,000	1.64	2.46	3.28	4.91	6.55
42-44,000	1.72	2.57	3.44	5.15	6.86
44-46,000	1.79	2.69	3.59	5.38	7.18
46-48,000	1.87	2.81	3.75	5.62	7.49
48-50,000	1.95	2.96	3.90	5.85	7.80
50-52,000	2.03	3.04	4.06	6.08	8.11
52-54,000	2.11	3.16	4.21	6.32	8.42
54-56,000	2.18	3.28	4.37	6.55	8.74
56-58,000	2.26	3.39	4.53	6.79	9.05
58-60,000	2.34	3.51	4.68	7.02	9.36
60-62,000	2.42	3.63	4.84	7.25	9.67
62-64,000	2.50	3.74	5.00	7.49	9.98
64-66,000	2.57	3.86	5.15	7.72	10.30
66-68,000	2.65	3.98	5.31	7.96	10.61
68-70,000	2.73	4.10	5.46	8.19	10.92
70-72,000	2.81	4.21	5.62	8.42	11.23
72-74,000	2.89	4.33	5.78	8.66	11.54
74-76,000	2.96	4.45	5.93	8.99	11.86
76-78,000	3.04	4.56	6.09	9.13	12.17
78-80,000	3.12	4.68	6.24	9.36	12.48
80-82,000	3.20	4.80	6.40	9.59	12.79
82-84,000	3.28	4.91	6.56	9.83	13.10
84-86,000	3.35	5.03	6.71	10.06	13.42
86-88,000	3.43	5.15	6.87	10.30	13.73
88-90,000	3.51	5.27	7.02	10.53	14.04
90-92,000	3.59	5.38	7.18	10.76	14.35
92-94,000	3.67	5.50	7.34	11.00	14.66
94-96,000	3.74	5.62	7.49	11.23	14.98
96-98,000	3.82	5.73	7.65	11.47	15.29
98-100,000	3.90	5.85	7.80	11.70	15.60

and for each additional 2000 square feet of area or increments thereof, and in accordance with the intensity of development classification of the property, the property shall be charged an additional amount per month as follows:

UNDEVELOPED	LIGHT DEVELOPMENT	MODERATE DEVELOPMENT	HEAVY DEVELOPMENT	VERY HEAVY DEVELOPMENT
.078	.117	.156	.234	.312

Section 5. The service charges herein established shall apply to services provided on and after June 7, 1977.

Section 6. The authority set forth in Ordinance No. 2274 shall apply to the service charges herein imposed.

Section 7. If any provision of this ordinance, or its application to any person or circumstance is held invalid the remainder of the ordinance or the application of the provision to other persons or circumstances is not affected.

Section 8. This ordinance shall take effect and be in force five days after its passage and legal publication.

PASSED by the City Council this 31 day of May, 1977, and signed in authentication of its passage this 31 day of May, 1977.

(SEAL)

Gary A Zimmerman
Gary Zimmerman, Mayor Pro Tem

Approved as to form:

William C Graves
William C. Graves, Assistant City Attorney

Attest:

Sharon S. Stewart
Sharon S. Stewart, Deputy City Clerk

Published: 6-4-77

RECOMMENDED DRAFT
STORM AND SURFACE WATER ADVISORY COMMISSION

TOPIC

Water Resources

GOAL

Preserve and enhance water resources.

OBJECTIVES

1. ((To)) Achieve good surface water quality where degraded surface water quality now exists by 1990.
2. ((Attempt to)) Provide a storm and surface water system capable of handling storm events up to 100-year in occurrence by 1990.
3. Remove surface water quality standard violations by 50 percent by 1990.
4. Re-establish self sustaining fisheries resources in Bellevue's lakes and streams by 1990.
5. Preserve ((all)) existing wetlands.
6. ((To)) Achieve rehabilitation of degraded aquatic and riparian habitats by 1990.
7. Adopt a comprehensive implementation program by 1985.

POLICIES

1. Retain existing open surface water systems in a natural state except when necessary to protect public health and safety on an area-wide basis.
2. Maintain good surface water

INTENT

The intent of these goals and policies is to manage Bellevue's water resources such that they remain clean, prevent public health and safety hazards, mitigate property damage and promote beneficial uses.

((DISCUSSION:)) BACKGROUND:

Bellevue's lakes, streams, wetlands, intermittent waterways and ground water aquifers are an important natural resource and compose elements of the local hydrologic cycle (see figure). Bellevue's surface waters are not used as a drinking water source. Open surface water beneficial uses are, in order of priority:

1. Habitat,
2. Storm water conveyance,
3. Open space and resource preservation,
4. Recreation, and
5. Aesthetics.

((The present trend of developing)) Further development in environmentally sensitive areas such as wetlands and floodplains will be halted. Bellevue's lakes, streams, wetlands and intermittent waterways will be preserved in a natural state for future generations to enjoy and use.

Groundwater aquifers are used for supplying water to lakes, wetlands and streams during the dry season and quality and rehabilitate degraded surface water quality using the best available technology and through appropriate controls on site development.

3. Restrict to the extent possible, surface water runoff to pre-development levels for all new construction and development ((to the extent possible)) using the best available technology.

4. Preserve and maintain the 100-year floodplain in ((a natural)) an undeveloped state except when necessary for area-wide storm water control projects.

5. Preserve and maintain wetlands in a natural state except when necessary for area-wide flood control.

6. Preserve aquatic and riparian habitats in a natural state and rehabilitate areas that have been degraded.

7. Conserve ground water resources to the extent possible using the best available technology except when groundwater creates public safety problems.

for a few private wells that supply drinking water.

Rainfall contributes to surface water and the groundwater table. Since Bellevue's climatic pattern includes more rainfall in fall, winter and spring than in summer, surface waters are naturally low in summer and higher during the rest of the year.

Land development by its nature cannot avoid changes to this natural hydrologic cycle. The land surface is transformed through clearing, grading, filling, excavation, compaction, covering with impervious surface, construction of conventional pipe drainage systems and planting ornamental landscaping. All of these activities decrease the land's capacity to absorb and retain water and the groundwater recharge potential. When this capacity is reduced, surface water runoff increases causing flooding and erosion.

Replacing natural overland or subsurface drainage with conventional pipe systems can cause flooding by hastening the delivery of rainfall into surface waters and can decrease groundwater recharge by limiting the amount of water seeping into the soil.

Flooding is also caused when eroded soil from cleared land or unstable slopes reduces the waterway's natural capacity to carry runoff water.

Construction and development activity within the floodplain is particularly damaging. By a combination of reducing the floodway capacity and creating more runoff from development the floodplain is no longer able to handle water flows and flooding results. ((creating property damage, public safety hazards and destroying aquatic and riparian habitat. However, some land uses such as open space, and recreation may not cause flooding problems when located within the floodplain. Other land uses such as agricultural or horticultural activities may cause minor flooding and some water quality problems.))

In recognition of this situation, the Federal Flood Insurance Program was created which guarantees protection for lands in flood hazard areas if certain eligibility requirements are met. The standard set by this program is for preservation of the 100-year flood plain. The 100-year flood plain is the area of land flooded by a storm which has a one percent probability of occurring in any year. ((Given Bellevue's numerous streams and floodplains, the City needs to regulate land uses and construction activities to minimize the potential for flooding and maintain its eligibility for flood insurance.))

Under this program some floodplain development is allowed such as streets, parking lots and buildings on piling, some filling of the floodplain and channelization of streams. These practices have resulted in public hazards due to flooded streets, parking lots and buildings located in the floodplain; increases in stream velocities causing erosion, scour and sedimentation; property damage and the destruction of aquatic and riparian habitat. Predicted changes to the floodplain and its ramifications as a result of floodplain development are imperfect and there is substantial public risk in approving such developments. The high public cost of correcting problems by allowing these uses is mostly clearly shown in the City's Comprehensive Drainage Plan and Capital Improvement Program for which $10 million is only the initial cost. Some land uses, such as open space, recreational, agricultural or horticultural activities, may not cause problems to such a high degree. Given Bellevue's numerous streams and floodplains, the City needs to regulate land uses and land alteration activities to minimize the potential for flooding.

Water quality also changes as a result of land activities. Good water quality deteriorates when pollutants such as sediment, nutrients, organic material and toxicants are either dumped or discharged directly into the surface water or washed in by runoff. Direct dumping or discharge is caused by accidents and improper disposal of waste materials. Contaminants from land use activities and traffic are washed off impervious surfaces. In addition, rainfall carries pollutants from the air. Groundwater can become contaminated when polluted surface water percolates through the soil.

Polluted water reduces the number of uses of the resource, causes public health hazards, destroys aquatic and riparian habitat and detracts from its aesthetic appeal.

Control of pollutants at their source is the first and best method for prevention of water quality problems. Other water pollution control measures may be needed when source controls have failed or cannot achieve the desired water quality.

Limitations and conditions on land activities can minimize the effect of development on Bellevue's lakes, streams, wetlands, intermittent waterways and groundwater resources. Land use regulations which prevent or limit development in environmentally sensitive areas can reduce flooding, erosion and sedimentation. Land use regulations could include measures which identify areas not suitable for development and controls on development such as lot coverage, density, location of uses, vegetation preservation and replanting with appropriate vegetation. During construction, measures such as erosion and runoff control techniques, restricting time of year for construction activities, water treatment and revegetation reduce erosion, flooding and sedimentation.

((All of))These measures are of a mitigative and preventive nature. The extent of mitigation for control of drainage problems is limited to what the best available technology can achieve. ((and is the criterion for the reasonable allowance of changes to the water resource.)) Engineered designs should improve the effectiveness of natural systems rather than negate, replace or ignore them. The best available technology will emphasize the use of non-structural or "natural" engineering approaches. These approaches should be consistent with natural resources and processes, and preserve and enhance the natural features of Bellevue.

IMPLEMENTATION PLAN

1. Adopt Land Use Regulations.
    - A. Develop setbacks for land uses from wetlands, open surface waterways, streams and lakeshores.
    - B. Limit impervious surface coverage.
    - C. Require the rehabilitation of water quality as degredation occurs.
    - D. Adopt new land use definitions.
    - E. Adopt ((environmental constraint)) sensitive area maps.
    - F. Prohibit development within floodplains and wetlands.
2. Adopt a storm and surface water code, regulations and standards.
    - A. Protect((ing)) the open surface water system.
    - B. Strengthen the floodplain ordinance to ((maintain eligibility for the Federal Flood Insurance Program and))preserve the floodplain and maintain eligibility for the federal flood insurance program.
    - C. Prohibit((ing)) direct dumping or discharge of pollutants to surface waters.
    - D. Control((ling)) construction practices to minimize erosion, surface water shade removal and disturbances to water courses.
    - E. Require((ing)) pollutant source controls and treatment.
    - F. Control((ling)) land clearing, grading, filling, excavation, compaction, covering with impervious surfaces and construction of drainage systems to minimize adverse hydrologic effects.
    - G. Define((ing)) the best available technology for storm and surface water quantity and quality control.
    - H. Protect((ing)) the aquatic, riparian, and wetland habitats.
    - I. Define((ing)) area-wide benefits, public benefits and local benefits.
3. Develop and adopt a Storm and Surface Water Management Plan for the City.
4. Enter into interlocal agreements for the joint management of interjurisdictional surface waters.
5. Provide community education on water pollution, erosion and flood control.

6. Provide an emergency response program for water pollution and flood control.

7. Participate in the State of Washington ((pilot)) program for urban runoff water quality control.

8. Develop and adopt operations and maintenance standards and a program which minimizes pollution, erosion and flood damage from City properties and City activities.

9. Participate in ((furthering the state of the art in)) advancing the technology of surface water pollution, erosion and flood control.

RECOMMENDED DRAFT
STORM AND SURFACE WATER ADVISORY COMMISSION

TOPIC

Earth Resources

GOAL

1. Protect natural features such as steep slopes((,)) and soils from landslide potential and erosion hazard by managing development and land uses.

2. Preserve and enhance vegetation.

OBJECTIVES

1. ((To)) Improve the ((native)) indigenous landscape character of Bellevue by 1990.

2. Prevent development on unstable ground.

3. Preserve sufficient habitat to sustain naturally occurring wildlife populations in Bellevue.

4. Prevent sediment from leaving its site of origin during construction activities.

5. Adopt a comprehensive implementation program by 1985.

POLICIES

1. Regulate land use and development to be compatible with natural topographic, geologic, vegetational and hydrologic features.

2. Preserve existing indigenous ((forest)) vegetation for habitat ((aesthetic)) and ((habitat)) aesthetic purposes to the maximum extent possible.

3. Enhance or provide vegetation that is compatible with native character.

INTENT

It is the intent of these policies to achieve land uses and development practices that are compatible with Bellevue's variety of environments. These development practices should ((strive to)) preserve rather than overcome ((reflect natural environments rather than overcome)) natural environments. ((constraints)). ((A second intent of these policies is to identify potentially hazardous areas.))

A second intent of these policies is to identify potentially hazardous areas. The present trend of developing in environmentally sensitive areas such as steep slopes, landslide hazardous areas and riparian and forest habitat will be slowed down and in some instances halted.

Many of Bellevue's steep slopes, forested covered hillsides and ravines, open meadows and other unique and scenic natural features should ((will)) be preserved in open spaces. ((for future generations to enjoy and use.))

DISCUSSION:

Bellevue's natural environment is composed of a wide variety of land forms, soils, water courses and vegetation. The City's terrain ranges from steep hills and ridge lines to flat valleys and flood plains. Soil types vary from peat and loam in the lowlands to sand, gravel and till in the uplands. Some unstable soils are located in the wetlands and on steep slopes. Numerous lakes, streams, and wetlands, are found throughout the City.

4. Prohibit development on unstable land which includes land with slopes greater than or equal to 40 percent, and restrict development on ((other)) potentially unstable land.

5. Minimize and control soil erosion during and after construction through the use of the best available technology and other development restrictions.

6. Allow ((only non speculative land alterations.)) land alterations only for approved development proposals.

Native vegetation ((in the lowland)) ranges from that associated with wetlands to that associated with uplands. ((in the lowland ranges from wetland to woodland. Upland areas are generally forested.)) This diverse vegetative habitat supports a wide range of wildlife. ((mammals, reptiles and birds.)) The((se)) topographical, geologic, hydrologic and vegetation((al)) characteristics combine to produce an environment that in some areas of the City is compatible with ((suitable for)) residential, commercial or industrial development and in other areas of the City is not compatible with ((suitable for)) development.

((All)) Construction and development activities alter the natural environment. ((to some extent. In areas where the environment is suitable for development,)) The impact ((and cost)) of construction is less ((than)) in areas where the environment is compatible with development. ((unsuitable for development.)) Development and land use activities need to be regulated to protect ((the environment and to minimize)) in order of priority:

1. the Public health and safety ((hazards,))
2. the Environment((al destruction,))

((Based on slopes, geologic materials and soils,)) Bellevue can be divided into various land management categories which are based on slopes, geologic materials and soils. ((areas.)) The supporting background information on slopes, soils, geologic materials and wetlands is found in the Sensitive Areas Notebook. The first category includes land that is suitable for most types of development. Slopes are generally less than 15 percent. These slopes are stable, although slides may occasionally occur under special conditions such as prolonged periods of intense rainfall. Common amenities and expose soil to erosion. Wildlife habitat is destroyed by removing vegetation, compacting soil and filling in waterways. When wildlife habitat is destroyed the number of species living in the area declines.

Vegetation in Bellevue is an important visual amenity consisting of ((. The City contains beautiful views of)) forested ridges, wetlands, grassy meadows and lakeshores. The removal of vegetation ((decreases the City's scenic beauty and)) emphasizes the effects of urban development. Vegetation removal may also lead to erosion. Erosion causes property damage both on site through ((by the)) loss of topsoil, and ((downstream)) by depositing sediment on downstream properties and in waterways. This reduction in the natural capacity of waterways may cause((s)) flooding. Seasonally heavy rainfall in winter accelerates the erosion process. Delta formations due to sediment ladened storm water have become a serious and costly problem in Lake Sammamish and Lake Washington.

Limitations and conditions on land use activities can limit adverse effects on the environment. Land use regulations which prevent or limit development can reduce erosion, settlement, landslides and property damage, and preserve important natural features and ((visual)) amenities. Such regulations include limiting lot coverage and density, or requiring special engineering attention on steep slopes, limiting the amount of vegetation removed, and restricting the time of year for construction activities. ((lot coverage and density.))

During construction, measures such as erosion control techniques and revegetation are also needed to reduce erosion, settlement, landslides and property damage, and preserve wildlife habitat. All of these measures are of a mitigative and preventive nature. ((The extent of mitigation of erosion control measures and construction practices is limited to what the best available technology ((can achieve.)) should be used for construction practices and control of erosion.

underlying geologic materials are till and outwash. Alderwood, Everett, Ragnau and Indianola soils are found through the area. Development in this area poses the lowest risk of public health and safety problems, environmental destruction and property damage. Development regulations should concentrate on preventing soil erosion, unnecessary removal of vegetation and preserving natural features and ((visual)) amenities. ((An)) Important exceptions to this category are ((relatively flat)) areas with less than 15 percent slope underlaid by fine to medium grain materials. These areas do not generally support foundations or heavy loads and become unstable when saturated or subjected to earthquake shaking. Development in these areas should be restricted.

The second category includes land that may have certain hazards associated with it if developed. Slopes vary ((anywhere)) from less than 15 percent to 40 percent. The degree of development hazard depends upon the type of underlying geologic material. Areas underlaid by sand, gravel and till are relatively more stable than areas underlaid by silt and clay. Alderwood, Kitsap, Norma, Seattle and Snohomish are some of the soils located in this area. Localized areas of high water tables are also found here. Development in this area should be limited because of the risk to public safety and health, ((of public health and safety problems,)) the environment((al destruction)) and property.((damage.)) Development regulations should include special engineering studies detailing the problems of developing the site and surrounding area, site design requirements and erosion control measures.

The third management category ((area)) includes land where natural disruptions are highly probable under any circumstances. Slopes are generally greater than 40 percent and extremely unstable. Many of the slopes are associated with special underlying geologic materials such as permeable materials overlying less permeable materials. Springs and seepages from ground water tables located near the slope surface are common. Alderwood and Everett soils predominate. Development in this area should be prohibited because of the high risks of landslides, uneven settlement, and property damage. Engineering solutions to environmental constraints are not acceptable in this land management ((area)) category and are extremely costly and often inaccurate. Engineering solutions cannot predict with 100 percent accuracy the long-range problems caused by developing the land. The cost, both on and off site, to correct property and environmental damage can be quite large and is generally borne by the public.

Speculative land alterations are prohibited within the City. When land is cleared without being tied to a specific development proposal, several problems can occur. Soil is lost from the site by erosion, landslides and slumps can occur, and vegetation and wildlife habitat are destroyed. Property surrounding the cleared land can be adversely affected by these problems. ((The costs, both on site and off site, to clean up this environmental damage can be quite large and are generally borne by the public.)) Additionally more indirect adverse impacts can occur due to the inability to review or limit clearing in conjunction with a specific site design. With a definite proposal, grading can be restricted to the minimum required.

((All)) Construction and development activities alter the natural environment, destroy wildlife habitat, decrease ((important visual)) natural

IMPLEMENTATION ((MEASURES)) PLAN

1. Adopt Land Use Regulations

   A. Develop regulations which recognize environmental constraints.

   B. Develop a program to promote the ((establish a)) system of greenbelts throughout the City.

   C. Establish regulations that preserve vegetation.

   D. Establish land management categories ((slope stability classes)) and develop regulations compatible with each ((class)) category.

2. Adopt a Clearing and Grading Code, Regulations and Standards.

   A. Establish ((strict regulations to control)) construction practices ((to minimize erosion)) and ((develop)) land management regulations to minimize erosion.

   B. Determine and define the best available technology for erosion control.

3. Provide education on erosion control.

4. Adopt a Sensitive Areas Notebook which covers Bellevue's wetlands and steep slopes.

5. Enter into interlocal agreements for the joint management of interjurisdictional steep slopes and support steep slope controls of related governmental bodies.

9745H/94A

CITY OF BELLEVUE
Storm & Surface Water Utility Department

CUSTOMER ACTION REQUEST

REQUEST NO: ______ DATE RECEIVED: ___ MO ___ DAY ___ YEAR

ASSIGNED TO: ______ LAST NAME TIME ______

CONTACT ______ LAST NAME ______ FIRST NAME

ADDRESS ______

TYPE ☐ BASIN ☐ MAP ______ PARCEL ______ PHONE (W) ______

COORDINATES E 1,6 ______ N 2 ______ PHONE (H) ______

DESCRIPTION OF COMPLAINT OR REQUEST OR COMMENT (Describe location of event to accurately locate)

ADDITIONAL COMMENTS, SEE ATTACHED YES ☐ NO ☐ TAKEN BY ______

ACTION TAKEN (Precede each action by date. Include who responded, who was contacted, what was done, site visit work orders initiated, etc.).

ADDITIONAL COMMENTS, SEE ATTACHED YES ☐ NO ☐

TYPES
A - Advice
C - Construction
D - Development
F - Flooding
M - Maintenance
O - Referred
P - Private System
R - Rate
W - Water Quality

BASINS
C - Coal Creek
K - Kelsey Main Stem
L - Lakehurst
M - Meydenbauer Creek
N - Mercer Creek
P - Phantom Lake
R - Richards Creek
S - Rosemont
V - Valley Creek
W - West Trib. Kelsey
X - Vasa Creek
Y - Yarrow Creek

DATE RESOLVED ___ MO ___ DAY ___ YEAR

______
SIGNATURE - OPERATIONS MANAGER

Form No. 1202

ROUTING: WHITE-Data Entry, YELLOW-Project File, PINK-To File After Resolution

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